UNDERSTANDING SPATIAL PATTERNS OF PHYSICAL ACTIVITY: MEASUREMENT IMPLICATIONS FOR EPIDEMIOLOGIC RESEARCH

Katelyn Marie Holliday

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Approved by:

Kelly R. Evenson

Michael Emch

Annie Green Howard

Daniel A. Rodríguez

Wayne Rosamond

ABSTRACT

Katelyn Marie Holliday: Understanding Spatial Patterns of Physical Activity:
Measurement Implications for Epidemiologic Research
(Under the direction of Kelly R. Evenson)

Physical activity (PA) is linked to prevention of a spectrum of chronic diseases, compression of morbidity, and improved quality of life. Yet, most adults do not engage in the recommended amount of PA. Thus, identifying factors that increase PA is an important research focus. Researchers advocate use of theoretical frameworks, which propose that a variety of factors (e.g., environmental, social, and policy) work together to influence health behavior. The built environment is a factor suggested by theoretical frameworks that is of particular interest for PA given its potential as an intervention target at the population level. Due to the complex mechanisms by which built environment factors influence PA, their study has incorporated input from a range of disciplines which, while beneficial, has resulted in inconsistent exposure and outcome definitions, measurement practices, and analytic methods. These differences may contribute to the discrepancies observed in many exposure-outcome relationships and complicate comparison of results across disciplines. The focus of this research was therefore on informing three distinct methodological issues that involve identifying and appropriately measuring attributes of the built environment locations in which PA occurs. First, a PA location coding protocol was developed to increase the quality of published studies on the PA locations of adults and then implemented within a sociodemographically and geographically diverse participant population. Second, examination of the spatial overlap between residential buffers and newly proposed PA spaces was completed to inform interpretation of PA-built environment studies

with exposures derived from commonly used residential buffers. Finally, a recommendation for the number of GPS monitoring days needed to reliably estimate minutes of PA in various locations was developed. The substantive and methodological contributions of these three inter-related aims improves the PA locational context literature by facilitating current PA intervention development and urban planning through delineating the locational contexts in which diverse adults choose to be physically active. Further, these results guide future research to improve the methodological soundness of studies examining the locational context of PA. Taken together, these results provide useful information for researchers, health promotion specialists, and urban planners attempting to study and plan environments that support PA.

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LIST OF ABBREVIATIONS

BMI	Body mass index
CA	California
CM	Centimeter
CPSTF	Community Preventative Services Task Force
GIS	Geographic Information Systems
GPS	Geographic positioning system
ICC	Intraclass Correlation Coefficient
KM	Kilometer
M	Meter
MI	Mile
MVPA	Moderate to vigorous physical activity
NC	North Carolina
NHANES	National Health and Nutrition Examination Survey
NM	New Mexico
OH	Ohio
PA	Physical activity
SD	Standard Deviation
US	United States
VPA	Vigorous physical activity
WAAS	Wide Area Augmentation System
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

According to the World Health Organization, physical inactivity is the fourth leading risk factor for mortality globally (1). Recent analyses suggest that inactivity is responsible for 5.3 million annual deaths globally (2). It accounts for 21-25% of breast and colon cancer burden, 27% of diabetes burden, and 30% of ischemic heart disease burden as measured by disability adjusted life years (1). The United States Department of Health and Human Services states that there is strong evidence that physical activity (PA) lowers risk of early death, coronary heart disease, stroke, high blood pressure, adverse blood lipid profile, type 2 diabetes, metabolic syndrome, colon and breast cancer, weight gain, falls, and depression as well as decreased cognitive function among older adults (3). Despite these numerous benefits of PA, most Americans do not meet national guidelines. Recent analyses in the National Health and Nutrition Examination Survey (NHANES) found that only 10% of adults meet the recommended levels of PA as measured by accelerometry (4). Moreover, 32% (45% of those aged 65+) reported being completely inactive during leisure time in 2011 (5).

Given these trends, identifying factors that increase PA has become an important research focus. Researchers advocate use of theoretical frameworks, such as the Social Cognitive Theory and the Social Ecological Framework, when studying PA behaviors and developing health promotion programs (6, 7). Both of these frameworks propose that a variety of factors, including individual, environmental, social, cultural, and policy, influence behavior (6, 7). Causally, these factors interact with and are moderated by each other. For example, Kremers et al. outline a dual-process framework in which environmental factors can influence obesogenic behaviors directly through automatic, reactive processes or indirectly through behavior decision-making processes (8). Within this framework, individual characteristics, like sociodemographic factors and personality, may moderate the mechanism by which the environment influences PA as well as the strength of that influence (8).

The built environment is a factor suggested by theoretical frameworks that is of particular interest for PA given its potential as an intervention target at the population level. It has been defined as encompassing urban design, land use, and the transportation system and considers the patterns of human activity within the physical environment (9). Thus, questions about the locational context of PA and attributes of the built environment that support PA are primary questions of interest in this field. Given the complex mechanisms by which built environment factors influence PA, its study has incorporated input from a range of disciplines, including epidemiology, exercise and sport sciences, urban planning, geography, and health behavior (10). While input from these varied fields is beneficial, it has resulted in inconsistent exposure and outcome definitions, measurement practices, and analytic methods. These differences may contribute to the discrepancies observed in many exposure-outcome relationships. At the very least, they complicate comparison of results across studies and disciplines.

The focus of this research is therefore on informing three distinct methodological issues that involve identifying and appropriately measuring attributes of the built environment locations in which PA occurs. This research will provide useful information for researchers, health promotion specialists, and urban planners attempting to study and plan environments that support PA.

CHAPTER 2: STATEMENT OF SPECIFIC AIMS

Specific Aim I.

Specific Aim IA. Develop a protocol for identifying locations (e.g. roads, parks, recreation facilities, homes) in which adult participants engage in ten or more minute bouts of moderate to vigorous PA (MVPA) and vigorous PA (VPA) from concurrently collected Geographic Positioning Systems (GPS) and accelerometer data.

Specific Aim IB. Implement this protocol within the System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study. Explore whether results are modified by major sociodemographic factors (gender, age, race, education) as well as by body mass index (BMI), state of recruitment, and location of recruitment (park vs. home near park).

Hypotheses: Streets and homes will be the most common locations for MVPA. Location of MVPA differs by sociodemographic factors, with females, older adults, and those with lower education participating in MVPA nearer to home than males, younger adults, and those of higher education. Individuals recruited from parks are hypothesized to have more MVPA time in parks than those recruited from their homes.

Specific Aim II.

Specific Aim IIA. Examine the percent of MVPA bout minutes within various residentially-defined buffers (circular and network) for participants in the SOPARC GPS sub-study.

Specific Aim IIB. Develop spatial summarizations of MVPA occurring in bouts of at least ten minutes based on the concept of activity space, including 1) an overall PA space derived from mapping all bout-based MVPA GPS points over a three-week period at once in a single minimum convex polygon and 2) an individual bout-based PA space derived from mapping each individual bout of MVPA over the three-week period into multiple minimum convex polygons.

Specific Aim IIC. Examine what percent of residential buffers (circular or network) are covered by the PA spaces of individuals measured by GPS in the SOPARC GPS sub-study in order to determine what portion of residential buffers are used for PA.

Specific Aim IID. Examine what percent of PA spaces of individuals measured by GPS in the SOPARC GPS sub-study are covered by their residential buffers (circular or network) in order to determine what portion of PA space occurs within residential buffers.

Specific Aim IIE. Examine whether sociodemographic factors (gender, age, race, education) as well as BMI and state of recruitment moderate Specific Aims IIA-D.

Specific Aim IIF. Examine Specific Aim II A-E after exclusion of PA points occurring at the home. The built environment may indirectly influence PA at home, where a large proportion of PA occurs. For example, non-supportive built environments could result in reduced residential neighborhood PA and increased home PA. Yet, interest in the direct effects of the built environment on PA occurring outside of the home is also of importance. Therefore, examining both PA spaces that include home PA and PA spaces that exclude home PA is of interest.

Hypotheses: A substantial proportion of PA time will occur outside of traditionally-defined residential buffers. PA spaces will extend outside of residential based circular and network buffers, but at the same time will not include all of the space within these buffers.

Specific Aim III.

Determine the minimum required GPS wear time to reliably estimate bout-based minutes of usual PA in a variety of common PA location types in the SOPARC GPS sub-study. Hypothesis: The minimum required GPS wear time will exceed 4 days, the standard recommendation for measuring habitual PA among adults.

CHAPTER 3: REVIEW OF THE LITERATURE

This research contributes to several important methodological questions for the study of PA while also providing needed substantive data on the types of locations in which individuals are active. The first aim develops a location coding protocol designed to identify locations of PA from GPS points and implements the protocol within a sociodemographically and geographically diverse adult population. The second aim extends the methodologic methods for examining characteristics of the locations in which adult PA occurs by examining the appropriateness of commonly used residential buffers as summarizations of built environment exposures during PA. In this aim, PA space is proposed as a more accurate summarization of the spatial locations in which individuals complete PA. The spatiotemporal patterns of PA space in relation to residential buffers are then examined. Finally, the third aim derives a recommendation for the length of time a GPS should be worn when attempting to reliably estimate minutes of bout-based PA within a variety of common PA location types for adults, which is an important aspect of study protocol for future studies examining the locational context of PA and how built environment characteristics of those locations influence PA.

Locational Context of Physical Activity

The first issue addressed by this research concerns assessment of the locational context of PA. Traditionally, PA measures were limited to time spent in various PA levels as assessed through self-report (11). Several criticisms arose surrounding the accuracy of these methods given standard concerns of over-reporting (12-14). These concerns were amplified with the advent of accelerometers, which often resulted in markedly different conclusions when compared to self-report (4, 15). For example, Tucker et al. found that 62% vs. 10% of adults met current PA recommendations according to self-report and accelerometry, respectively, using 2005-2006 NHANES data (4). Despite the initial enthusiasm over accelerometers, recent commentaries have suggested that neither self-report nor accelerometers are able to perfectly measure PA. Rather, each has its own set of advantages and disadvantages that must be considered when choosing whether to use self-report, accelerometry, or a combination (13).

One component of PA that both self-report and accelerometers have thus far failed to fully address is describing the context in which PA occurs (10, 11, 16). Most widely used self-report questionnaires have simply not evolved to focus on contextual aspects, and research-oriented accelerometers are unable to gather this information (11). Some have suggested that combining self-report or ecological momentary assessment and accelerometry would be an ideal way in which to gather social and locational contextual information (13, 17). Others have pointed to the more recent advances in Global Positioning System (GPS) technology as another means of understanding the locational context in which PA occurs (16, 18-20). For example, a review suggests that GPS units produce quality data useful for identifying the locations in which participants are physically active (18). Similarly, another review concludes that combining GPS and accelerometers to identify locations of PA is a feasible and useful addition to PA research (16). Both of these reviews recommend that in order to better understand the environmental context of PA and subsequently develop appropriate interventions, researchers should first accurately identify the locations in which individuals are physically active (16, 18). Knowledge of the sociodemographic patterns of PA locations can be used to inform interventions, such as those recommended by the Community Preventative Services Task Force, when planning targeted interventions in communities.

Despite the recommendation to survey locational context of PA, few studies have examined the places in which individuals are physically active, particularly the places in which adults are active. Instead, researchers have relied on traditional, context-free methods that simply focus on time spent being physically active. The current body of literature is therefore missing important information that could be used to inform understanding of PA-built environment relationships and intervention development. The first aim of this research developed a protocol for classifying locations of PA from GPS data and then used this method to describe the locations of bouts of PA of adults in a five-site study. The work relies on previously collected concurrent accelerometer and GPS data. This method involved use of Google Fusion and Maps (Google Inc., Mountain View, CA), tools freely available to researchers across disciplines and geographic locations, allowing for creation and use of consistent methodology currently lacking in the field.

A small and complex literature currently describes the locations in which adults participate in PA (Table 1) (21-43). Studies of adults have largely been completed in the United States (US) and Australia. Of studies occurring in the US, most are single city or community studies or small regional studies and only two are nationally generalizable. As such, sample sizes vary dramatically, from small qualitative studies (n=29) to large national surveys (n=8844). Published studies were conducted from 1995-2013 and generally included participants from all age groups and both genders.

Most studies indicated that streets, homes, and neighborhoods were some of the most common locations in which adults were physically active. Studies that recruited participants from within or near parks tended to report higher park use (24, 27, 35). Unfortunately, the two nationally representative US studies are difficult to interpret in the context of current intervention planning. One was completed during 1999-2000 (22), potentially limiting usefulness of the data in the present day, and the other collapsed almost 40% of PA bouts into an “other” category, suggesting the need to further refine this category (29, 30). Despite these concerns, Dunton et al. do present results for percent of PA bouts by sociodemographic, seasonal, and temporal (day of week, time of day) categories, a strength as compared to the rest of the literature (29). For example, they report that men were more likely to exercise outdoors and at work whereas women were more likely to exercise at home (29). Also, outdoor and home based exercise was more frequent at older ages whereas exercise at work and gyms was more common at younger ages (29). Individuals with higher education were more likely to exercise at gyms than were those with lower education (29). Expected seasonal patterns were observed, with more US adults reporting outdoor bouts during the spring and summer and home bouts during the winter (29). They also report results by duration and intensity of PA (30). Vigorous bouts were most likely to occur at a gym or at home and moderate bouts were longest when occurring outdoors (30).

Unfortunately, the studies used a variety of definitions and methods in examining the locational context of PA, making comparisons and conclusions difficult. First, studies have varied in the type of PA assessed. Many focused on leisure time MVPA with fewer focusing on total MVPA, although inclusion of walking for transport, gardening, chores, and yard work varied by study. Second, the manner in which PA and locations of PA were assessed varied. Almost all studies relied on questionnaires, but the questionnaires varied from study to study. Only four used both objective accelerometer and GPS data. Third, the studies focused on different classes of locations. For example, some simply report on PA taking place in the home, neighborhood, or outside the neighborhood whereas others focused on use of specific types of facilities (e.g. streets, public open space, private recreation centers). Finally, the way in which results are reported varies by study, further complicating comparisons across some studies. For example, a large number of studies simply report the percent of respondents who indicated that they use a particular facility (yes/no) whereas others report the percent of MVPA time spent in a particular facility.

Reviewing studies investigating the locations in which all adults are physically active indicates that a wide variety of methods have been used to examine this question. The studies use different definitions of PA, assess PA in different ways, have different conceptual focuses for PA locations (general versus specific), and assess use of these locations in different ways (Table 1). Some studies have used self-reported recall to assess both PA and location, others have used only device-based measures (accelerometers and GPS), and others have combined self-report and devices (Table 1). In general, device or combined device and self-report based measures have been more common in studies of children whereas self-report methods have been more prevalent with adults. Studies that report very specific types of locations have generally used self-report to identify locations whereas those focusing on general locations (home, neighborhood) more commonly used GPS to identify locations. Two notable exceptions are studies completed on children in England, where researchers were able to link GPS data with detailed geographic information system (GIS) data to identify specific types of locations (44, 45). Unfortunately, this level of detailed GIS data is not often available in other locations.

Overall, this review suggests that a significant and innovative addition to this body of literature would include several key features. Namely, a device-based study of United States (US) adults from an expanded geographic scope is notably missing. This type of study would readily allow for examination of the locational context of total MVPA time, an understudied component of this literature. Further, as in Dunton et al. (29, 30) results should be presented by sociodemographic categories to allow comparison across different groups. An important departure from the work by Dunton et al. would be refining location categories to prevent a large "other" category. The proposed Google Fusion and Maps (Google Inc., Mountain View, California) protocol (Appendix 1) combined with the available data for the SOPARC GPS sub-study, concurrent accelerometer and GPS data from 5 geographically distinct US cities, therefore helps to fill this gap.

Measuring Built Environment Attributes that Influence Physical Activity: Residential Buffers and the Concept of Activity Space.

The second issue addressed by this research concerns the way in which attributes of PA environments are measured. Built environment exposures are typically assigned using the participant's residential address, either by using an administrative boundary (e.g. zip code, census tract) or by creating a buffer around the residential address (e.g. a circular distance-based buffer or a road network distance-based buffer) (19, 20, 31, 46-62). Indeed, a systematic review of the literature indicated that 90% of studies on the relationship between contextual environmental factors and cardiometabolic risk factors focused solely on the residential environment (60). This residential-based exposure assignment method is at odds with the concept of activity space, which represents the overall geographical area in which individuals spend time in their day-to-day lives (63, 64).

Many authors have been critical of the theory underlying use of residential-based demarcations, indicating that they allow for substantial misclassification of exposure leading to potential inconsistent or weak effects (10, 19, 20, 31, 46-59, 65). A review on the relationship between obesity-related outcomes and environmental correlates postulated that many of the inconsistencies they observed in the literature were caused by methodological issues surrounding neighborhood definitions and the resulting derivation of environmental attributes (48). Further, residential-based exposure assignment methods has received criticism from both the geography and public health fields, being called, for example, "place-based" instead of "people-based" (61) and the "local" (53) or "residential" (46) "trap", indicating their failure to measure exposures from the locations in which people actually spend time.

In addition to the aforementioned theoretical criticisms, studies have also demonstrated that choice of neighborhood definition impacts associations between environmental attributes and health and behavior outcomes (19, 57, 66, 67). For example, choice of buffer type (circular vs. road network) substantially influenced results and even overall conclusions for factors associated with walking (19). In a simulation analysis, researchers used both residential neighborhood and individually defined activity spaces to construct environmental exposures (57). They found that neighborhood definitions can systematically and unpredictably bias associations (57). Inagami et al. showed that the effect of a residential neighborhood disadvantage score on self-rated health was strengthened after accounting for non-residential exposure to disadvantaged areas (59). Jago et al. showed that size of neighborhood buffer [400 meter (m) vs 1 mile (mi)] influenced associations between environmental features and PA among adolescent boys (66).

Other research has shown that associations between residential neighborhood contextual factors and *total* PA are diluted as compared with associations between residential neighborhood contextual factors and *residential neighborhood* PA (31, 54, 58, 68). In support of this difference, work by several authors showed that contextual environmental exposures created from residential neighborhood areas were poorly correlated with the same features derived from GPS defined activity spaces (49, 52) and non-home environments (55).

Others have examined this issue by focusing on the amount of time individuals actually spend in their residential neighborhoods. This research has demonstrated that individuals spend considerable time outside of their residential neighborhoods (20, 31, 62, 69, 70). For example, ethnographic work completed on 43 Boston families demonstrated that only 6% of destinations were located within the home census tract whereas 20% were located in adjacent tracts and 74% in non-adjacent tracts (62). Research in New York City found that only 35% of GPS trip points were within a 1 kilometer (km) buffer of home (70).

One potential way to address concerns over using residential buffers is to consider built environment exposures within a person's activity space. Activity space is defined as the overall geographical area in which individuals spend time in their day-to-day lives, instead of being limited to a residential buffer of a predetermined size and shape (63, 64). Several studies have examined the overlap between residential based exposure areas (e.g. buffers and administrative boundaries) and activity space (20, 49, 55, 62, 71, 72). These studies have uniformly found that activity space is much larger than traditional residential-based demarcations, with a significant amount of time being spent outside of the home neighborhood. For example, Hirsch et al. found that a 0.5 mile circular residential buffer covered only 16.8% of older adult activity space (72). At the same time, researchers have suggested that activity space may be directional (46), leaving large areas of the traditional residential-demarcations unused. A study of children's daily destinations reached by active transport demonstrates this potential, with authors reporting that the majority of children used less than 25% of 800 and 1600 meter circular residential buffers (71). Similarly, work with teenagers suggested that PA locations originating at home and reached through active transport formed a directional pattern through the 0.5 and 1 mile circular residential buffers, with approximately 50% of the 0.5 mile buffer area visited and virtually none of the area outside of the one mile buffer (73). Taken together, these studies have generated concern over the common practice of assigning built environment exposures based on residential demarcations.

The main criticism of residential-based demarcations from both theory-based work and practical demonstrations is that they fail to align the spatial assessment of environmental attributes with the spatial assessment of health behaviors (10, 46, 54). Yet, few studies have examined the spatial overlap between activity space related to specific health behaviors and neighborhood buffers. Thus, the narrower concept of *physical activity space* of individuals is distinct from activity space in that *physical activity space* is the spatial areas in which individuals complete bouts of PA whereas activity space represents all locations visited by an individual regardless of the specific activities undertaken at those locations. For example, the Villanueva (71) and Hirsch (72) et al. studies described above define activity space based on all destinations reached through active transport or all measured GPS points rather than only using locations at which participants were physically active, making these studies of activity space and not *physical activity space*.

A small number of studies have attempted to examine the overlap between experienced PA time and residential-based demarcations (Table 2). One study of highly selected individuals (highly educated, regular trail users recruited from a Massachusetts trail) found that almost 70% of MVPA occurred outside of a 1 km home buffer and 80% occurred outside of a 1 km work buffer (31). In a convenience sample, Rodríguez et al. found that 24% of MVPA bouts occurred outside of a 1 km home buffer; although a significant amount of GPS data were missing (28). Hillsdon et al. found that 60% of light, moderate, and VPA occurred outside of a 0.5 mile residential buffer among adults from North West England (69). Finally, in a systematic household sample in Waterloo, Ontario, 39% of MVPA bouts were located outside of municipally-defined neighborhood planning district boundaries (33, 34). This small body of literature suggests that a significant proportion of total MVPA time may occur outside of traditionally used residential-based exposure areas. However, the identified studies were few in number and would benefit from the addition of geographic and demographic diversity of participants to allow examination of potential differences by sociodemographic factors. Further, these studies provide little information on the spatial overlap between the spaces in which PA occurs and residential buffers.

Given the various criticisms of residential buffers, many authors have called for assignment of contextual exposures that better align with the spatial locations in which individuals spend time (10, 16, 18-20, 31, 47, 48, 52-58). Understanding the scale at which locations impact different health behaviors and outcomes is a major challenge in advancing the literature concerning contextual influences on health (10, 47, 53, 56). Many have suggested that GPS enabled devices could be used to more accurately measure these environmental contexts (16, 18, 20, 31, 47, 48, 50, 52, 55, 56, 58, 61, 62, 68).

Despite this consensus, many researchers use one of the residential based exposure assignment methods as studies involving GPS can be costly, time-intensive, and introduce advanced data management and manipulation challenges. Further, many studies reviewed in the previous section have also reported that the home and neighborhood are some of the most common locations for PA among adults (17, 22, 23, 25, 26, 33, 37-43). This contextual information suggests that while residential-based demarcations may be inaccurate for activity space, they have the potential to accurately define PA space. However, the nature of the differing methodologies used in the PA locational context literature discussed previously makes it difficult to draw conclusions about the true frequency of PA at or near the home, thus complicating understanding of the appropriateness of residential buffers in relation to PA space. In particular, many of the locational context studies do not focus on total PA time spent in different locations. Instead, these studies often report solely on leisure-time PA and report results as the percent of respondents indicating that they are physically active in a given location (Table 1).

The second aim of this research therefore assessed the percent of PA time spent within residential buffers as well as the degree of spatial overlap between the narrower concept of *physical activity* space of individuals , that is the spatial areas in which individuals complete bouts of PA, measured by GPS over a three-week period, compared to traditional residential-buffers. Results were stratified by major sociodemographic factors (gender, age, race, education) as well as by BMI and state of recruitment as previous studies have not provided this level of detail. These results can help researchers understand the potential impact of choosing the various residential buffers to assign built environment exposures and may indicate which, if any, of these methods accurately represent the PA spaces of adults. Further, these methods could be followed to develop activity spaces specific to other health behaviors, such as the food or tobacco environment.

Use of Geographic Positioning Systems to Reliably Measure Locations of Physical Activity: How Many Monitoring Days are Needed?

The final issue addressed by this research concerns the use of GPS to measure PA locations, both for understanding the specific locations in which PA occurs and for estimating built environment exposures. As GPS is a more recent technological advancement in the study of PA, few best practice recommendations have been created for researchers (58). Specifically, there is no current recommendation for the number of measurement days needed to reliably estimate minutes of PA in an individual’s usual locations of PA with the use of GPS devices.

These types of recommendations exist for tools like accelerometers (74), and, in the absence of a GPS recommendation, researchers have often relied on these accelerometer recommendations when determining wear time for GPS (18, 58). Yet, a review of PA studies using GPS devices found that wear time varied drastically, from 40 minutes to 12 days (mean 4 days), and that inclusion of weekdays vs weekend days was inconsistent (18). Therefore, the need for monitoring length guidelines for GPS use in PA research has been indicated by several authors (16, 18, 58).

Some have suggested that wear time may need to be longer to study locations of PA, particularly in order to capture infrequently used locations (58). The final aim used data from participants who concurrently wore a GPS and an accelerometer for up to three weeks to determine the minimum number of days needed to reliably estimate bout-based minutes of usual PA in a variety of common PA locations. This provides important study planning information for minimizing monetary cost as well as participant burden.

Table 1 Summary of Studies Examining the Locations in which Adults are Physically Active

Study	Location (sampling)	Year	N	Age	% Men	Type PA	Time Frame	PA assessment Question/Device	PA assessment Epoch	Location Assessment Question/Device	Location Assessment Epoch	Results
Giles-Corti 2002	Perth, Australia (probability cluster sample; 18-59, employed, no PA in work, no medical PA restriction, lived >1 year in home, English-speaking)	1995-1996	1773	18-29: 26.2% 30-39: 28.4% 40-49: 27.1% 50-59: 17.2%	32	LTPA (vigorous, light to moderate) include transport walking and gardening	Past 2 weeks	Survey module modified from "major Australian studies"	n/a	Survey module: queried use of list of facilities in prior 2 weeks	n/a	<u>% of Respondents, n=1773</u> 45.6% Streets 28.8% Public open space 22.7% Beach 10.8% Gym/exercise center 8.9% River 8.9% Swimming pool 8.7% Sport or rec center 7.1% Tennis court
Brownson 2001	United States (population based, modified BRFSS sampling scheme, oversampled on low income)	1999-2000	1818	18-29: 27% 30-44: 30% 45-64: 26% 65+: 16%	33	Total MVPA (work, transport walking, leisure)	NR	Questionnaire: BRFSS, National Health Interview, and more	n/a	Questionnaire	n/a	<u>% of PA Respondents, n=?</u> 66% Neighborhood Streets 37% Shopping Mall 30% Park 25% Trail 25% Treadmill 21% Indoor Gym
Huston 2003	6 North Carolina counties (population based sample, non-institutionalized adults)	2000	1796	18-29: 23.3% 30-44: 33.2% 45-64: 28.5% 65+:15.0%	48	2 most common LTPA	Past month	BRFSS Exercise Questions	n/a	Where do you usually take part in these 2 activities? *Open ended then categorized	n/a	<u>% of PA Respondents, n=1214</u> 41.7% Streets/sidewalks 37.6% Home (indoors or yard) 10.5% Private rec facility 9.6% Workplace rec facility 8.6% Public park 3.8% Other public rec facility 2.8% School facility or grounds 2.7% Greenway/trail 1.4% Golf course 1.1% Shopping mall 0.9% Place of worship 6.0% Other

Deshpande 2005	12 rural towns in Missouri, Tennessee, and Arkansas (random digit dial survey of numbers within 2 mile radius of walking trail; subsample of those with SR diabetes and regular activity)	2003	136	20-39: 9.6% 40-64: 52.2% ≥65: 38.2%	32	Regular PA (≥30 min at least 5 days/ week)	Current	Modified BRFSS questionnaire	n/a	Questionnaire, in last 30 days on how many days did you use the nearest...? Then categorized into yes/no use	n/a	<u>% of PA Respondents, n=136</u> 38.2% Park 25.0% Recreation center 31.6% Trail 15.7% School 23.5% Health club 33.8% 0 facilities 47.1% 1 or 2 facilities 19.1% 3 or more (up to 6) facilities
Rodríguez 2006	Chapel Hill, North Carolina (matched neighborhoods)	2003				Non-work MVPA	Usual week	BRFSS Exercise Questions	n/a	What percent of MVPA time is in each category?	n/a	<u>% of Total Non-Work MVPA Time</u>
	Conventional Single Family		185	Mean: 46.9	63							35.9% Home 26.7% Neighborhood 37.4% Out of neighborhood
	New Urbanist Single Family		142	Mean: 45.0	52							28.0% Home 41.8% Neighborhood 30.2% Out of neighborhood
	New Urbanist Multifamily		66	Mean: 36.7	29							22.3% Home 47.2% Neighborhood 30.5% Out of neighborhood

Sugiyama 2009	Adelaide, Australia (two-stage; 1- spatially based neighborhood sample, 2-random address within neighborhood)	2003-2004	2194	Mean: 45.5	36	Leisure MVPA	Past Month	Questionnaire: Number of days	n/a	Questionnaire: Number of days in each location		<u>% of Total Days</u> 35% Streets near home 13% Streets near work 13% Park 11% Home or yard 8% Outdoor Rec Setting 8% Gym 3% Streets elsewhere 3% Pool 2% Other indoor facility 2% Work 2% School
Cohen 2007	Los Angeles, California (two part sample: park users, nearby residents)	2003-2004				Exercise	NR	Survey	n/a	Survey	n/a	<u>% of Respondents, n=713; 605</u>
	Park Users (systematically selected during park visits, active and sedentary users)		713	36	63							3% Health club “most common” Park
	Nearby residents (randomly selected by address within 2 miles of park)		605	39	50							6% Health club “most common” Park
Rodríguez 2005	Chapel Hill, North Carolina (convenience through email/fliers)	2004	35	Mean: 31.9	40	10 min MVPA bouts, 30% tolerance	3 days	ActiGraph 7164, Swartz cutpoint	1 min	Garmin Foretrex 201	1 min	<u>% of Total MVPA Time</u> 29% outdoors in neighborhood 24% outdoors out of neighborhood 0% indoors (14% poor GPS, 33% no GPS)

Dunton 2008	United States (nationally representative of 44 million non-institutionalized adults who engage in exercise on any given day in 2003-2006)	2003-2006	8844	21-34: 18% 35-44: 29% 45-59: 28% 60+: 24%	53	Sports or exercise	24-hour recall	American time use survey; record every activity over past 24 hours, coded into sports/exercise category	n/a	"Where were you while you were [activity]?" 26 categories, then collapsed to 6	n/a	<u>% of Exercise Bouts*</u> 25% Outdoors 25% Home 3% Work 8% Gym 36% Other 3% Unusual location
Troped 2010	Massachusetts (regular trail users recruited from trail)	2004-2005	148	Mean: 44	47	MVPA; Cutpoint: 1952	4 days (2 week and 2 weekend)	ActiGraph 7164	1 min	GeoStats Wearable GeoLogger (only wore outside)	1-5 sec	<u>% of MVPA Time</u> 33.3% 1 km home buffer 18.1% 1 km work buffer (n=80 subsample)
Schipperijn 2013	Odense, Denmark (random mail sample of the central city study area)	2005	1305	17-29: 36% 30-39: 21% 40-49: 15% 50-59: 14% 60-69: 9% 70-81: 5%	45	PA/sport/exercise	General	Questionnaire: Times per week (categorical)	n/a	Questionnaire: Times per week in each location	n/a	<u>% Respondents, n=1305</u> 74.3% Outdoors ≥ 1x/week 45.7% Nearest urban green space ≥ 1x/week
Kaczynski 2009	Waterloo, Ontario, Canada (systematic (nth household) sample of 4 neighborhoods)	2006	384	45.8	37	Total MVPA (>10 min episodes)	1 week	PA log booklet (indicate intensity: mild, moderate, strenuous)	n/a	PA log booklet (indicate location-open ended, then categorized)	n/a	<u>% of Bouts</u> 33% Neighborhood 29% Home/yard 39% Other 8% Park 3% Trail 1% Park and trail 6% Neighborhood park 2% Neighborhood trail

Stanis 2009	Los Angeles, California; Chicago, Illinois; Minneapolis, Minnesota (parks chosen by attributes, adult users systematically approached)	2006				MVPA	NR	Questionnaire modeled after BRFSS and International PA Questionnaire	n/a	Questionnaire: where usually do PA from list of options		<u>% of Respondents, n=924; 802</u>
	Urban Park		924	Mean: 37.7	46							59% This site 32% Home 23% Different Park 19% Gym 8% Work 6% Neighborhood 4% Other
	Remote Park		802	Mean: 40.8	55							15% This site 51% Home 34% Different Park 23% Gym 10% Work 14% Neighborhood 5% Other
Dunton 2012	Chino, California (convenience sample of parent-child pairs; here report parent/joint results)	2009-2010	219	Mean: 39.6	12	MVPA Cutpoint: 2020 (3 MET)	1 week (non- school hours analyzed)	ActiGraph GT2M	30 sec	GlobalSat BT-335 Bluetooth GPS data logger; classified by land use type	30 sec	<u>% of MVPA time</u> Joint MVPA / P-Only MVPA Residential 35 / 76 Commercial 24 / 7 Open Space 20 / 10 Educational 14 / 4 Public Facility 7 / 3 Other 1 / 1
Kegler 2013	4 rural Georgia counties (recruited active participants from a previous study)	2010	29	Mean: 55.9	66	PA or exercise	Typical	N/A	n/a	Semi-structured interview, asked where typically do PA or exercise		<u>Qualitative study</u> “Most common location home, including yard, followed by neighborhood. Roads primary neighborhood resource”

Zhu 2013	Austin, Texas (email through community listserv)	2013	148	Mean: 44	33	NR	Before/ after move to planned community	Possibly modified International PA Questionnaire	n/a	Questionnaire	n/a	<u>% of Respondents, n=148</u> <u>Before</u> <u>After</u> Nearby street 62 80 Park 34 77 Non-park trail 16 54 Home 16 54 Gym 44 26 Work 18 16 Greenspace 5 15 Other 6 7 Mall 4 3 School 9 2
Brown 2013	Esk, Mareeba, Mount Isa; Queensland, Australia (random by age/sex groups)	NR	1219	Mean: 46.7	42	Walking and leisure MVPA	Past Week	Questionnaire: Active Australia	n/a	Questionnaire	n/a	<u>% of Respondents, n=1219</u> 49% Home 43% Near Home 26% Work 18% Elsewhere
Bull 2000, McCormack 2003, Milligan 2007, Rosenberg 2010	Western Australia (stratified random telephone sample)					MVPA	Last week, at least 10 minutes	Questionnaire (somewhat similar to NHANES format)	n/a	If PA last week, what facilities did you use?	n/a	<u>% of PA Respondents, n=2770; 2761; 2938; 2948</u>
		1999	3178	18-29: 21% 30-44: 34% 45-59: 26% 60+: 20%	43							54% Street/footpath 42% Home 7% Cycle/Walk Path 11% Gym/Health/Rec 10% Public Park 10% Beach -- Public Pool -- Work -- Shopping Center
		2002	3200	18-29 15%: 30-44: 30% 45-59: 28% 60+: 26%	47							57% Street/footpath 50% Home 14% Cycle/Walk Path 14% Gym/Health/Rec 18% Public Park 12% Beach 7% Public Pool -- Work -- Shopping Center

		2006	3361	18-29: 12% 30-44: 26% 45-59: 32% 60+: 30%	50					48% Street/footpath 50% Home 25% Cycle/Walk Path 20% Gym/Health/Rec 17% Public Park 11% Beach 6% Public Pool 5% Work 1% Shopping Center
		2009	3363	18-29: 9% 30-44: 22% 45-59: 32% 60+: 37%	50					33% Street/footpath 55% Home 31% Cycle/Walk Path 20% Gym/Health/Rec 15% Public Park 8% Beach 5% Public Pool 12% Work 7% Shopping Center
Liao 2015	Chino, California	2011	113	23-73	30	MVPA (2020 cutpoint)	4 days	EMA/Actigraph GT2M	EMA	54% Home 18% Outdoor, Park 22% Outdoor, Other 10% Other
Hurvitz 2014	King County, Washington	2008-2009	611	<40: 22% 40-65: 65% >65: 13%	39	MVPA	7 days	ActiGraph GT1M	GlobalSat DG-100	80% near (125-1666 m from home) or away (>1666 m) from home, 20% home

Abbreviations: BRFSS, Behavior Risk Factor Surveillance System; EMA, ecological momentary assessment; GPS, geographic positioning system; IPAQ, International Physical Activity Questionnaire; LTPA, leisure time physical activity; Min, minute; MVPA, moderate to vigorous physical activity; N, number; n/a, not applicable; NHANES, National Health and Nutrition Examination Survey; NR not reported; PA, physical activity; SR, self-reported

Table 2. Studies examining the overlap between actual physical activity space and traditionally assigned spaces

	Location	Year	N	Age (mean)	% Men	Duration	Location Measurement	Physical Activity Measurement	Results
Troped 2010	Massachusetts (convenience sample regular trail users recruited from trail)	2004-2005	148	44	47	4 days (2 week and 2 weekend)	GeoStats Wearable GeoLogger (only wore outside)	ActiGraph 7164; MVPA; Cutpoint: 1952	66.7% of MVPA occurred outside of a 1 km home buffer and 81.9% occurred outside of a 1 km work buffer (work n=80 subsample) .
Yin 2013	Erie County, New York (random sample)		40	Range: 10-15	50	1 week	Garmin Fortrex and diaries; pertinent points corresponding to PA used to create a convex hull activity space (smallest polygon including all points)	Biotrainer accelerometer; **only included PA data originating at home** (i.e. couldn't drive somewhere first and then be active)	Mostly graphical and non-quantitative results. Compared physical activity space graphically to various circular buffers. Noted that circular buffer areas not used for PA uniformly, often used uni-directionally. Found that only ~50% of 20x20 foot cells found ½ mile from home were in the weekly PA space and cells ≥1 mile from home were never included in the PA space. Suggest 0.3 mile radius more appropriate as most cells were included in the PA space for at least 1 visit.
Rodríguez 2005	Chapel Hill, North Carolina (convenience through email/fliers)	2004	35	31.9	40	3 days	Garmin Foretrex 201	ActiGraph 7164, 10 min MVPA bouts, 30% tolerance, Swartz cutpoint	29% of total MVPA time occurred outdoors in a 1 mile buffer around residential address, 24% occurred outdoors out of the 1 mile buffer, 0% occurred indoors (14% poor GPS, 33% no GPS)
Kaczynski 2009	Waterloo, Ontario, Canada (systematic (nth household) sample of 4 neighborhoods)	2006	384	45.8	37	1 week	PA log booklet (indicate location-open ended, then categorized)	Total MVPA (>10 minutes episodes), PA log booklet	61% of bouts were in municipally-defined neighborhood planning district boundaries, 39% were outside these boundaries
Hillsdon 2015	North West England		195	18-91	42	7 days	Qstarz BT-Q1000XT	ActiGraph GT1M	60% LMVPA outside 0.5 mi residential buffer

Abbreviations: km, kilometer; LMVPA, light, moderate, vigorous physical activity; MVPA, moderate to vigorous physical activity; PA, physical activity

CHAPTER 4: OVERARCHING METHODS

Study Population

This study used data collected as part of the System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study. The initial data collection involved recruitment of participants from five communities: Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania. Participants (n=248) were recruited from within six (seven in the case of Los Angeles) key parks in each of the communities (n=198, 80%) as well as from residences located within one mile of these parks (n=48, 19%) (Table 3). Participants were excluded if they were <18 years old, non-English speaking, or non-ambulatory. Enrollment occurred in the spring, summer, and fall from May 2009 to April 2011, with most participants enrolled in 2009 (n=94) and 2010 (n=148) and only 4 enrolled in 2011 (Table 3).

Participants were asked to concurrently wear an accelerometer to measure PA and a GPS to measure location for three consecutive 1-week periods. Details of the accelerometer and GPS are discussed in detail below. In addition, study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height of participants at enrollment. Participants were compensated $200-225 after participation. Further participant recruitment and study details are available elsewhere (75-77). Study protocols were approved by appropriate study site affiliated institutional review boards and participants provided written informed consent.

Enrolled participants were aged 18-85 years [mean (SD): 40.5 (15.8)] and 44% were male. Minority groups were represented in the sample (26% Non-Hispanic Black, 15%

Hispanic, 9% Other) as were individuals from varied educational backgrounds (23% ≤high school education, 23% some college, 34% college degree, 21% post-secondary). BMI was evenly distributed, with 36% under or normal weight, 31% overweight, and 33% obese [mean BMI (SD) 28.3 (7.0)]. Although SOPARC purposefully attempted to recruit individuals from varied backgrounds, there were some differences by study site. For example, most African Americans were recruited in Ohio and Pennsylvania (71%) and most Hispanics from New Mexico and California (78%). Additionally, a large proportion of the individuals with post-graduate education were recruited from the North Carolina site (41%) and 67% of those with a high school education or less were recruited from Pennsylvania and Ohio.

Outcome Assessment

Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip for three consecutive 1-week periods (75). The ActiGraph GT1M, a capacitive accelerometer, was used to measure acceleration in the vertical plane by recording measurable changes in voltage that were proportional to the initial acceleration (78).

The ActiGraph GT1M has been found to have acceptable reliability as evidenced by low (<5%) coefficient of variations in tests both across and within units (79). In a controlled lab setting, Silva et al. tested intra- and inter-instrument reliability of 50 ActiGraph GT1M units with a mechanical shaker (79). They observed good reliability for measuring counts (CV_{intra}=2.9% and CV_{inter}=3.5%) and steps (CV_{intra}=1.1% and CV_{inter}=1.2%) under a 15-second epoch (79). Importantly, they did not observe batch effects or evidence of systematic trends in variation with increasing intensity of acceleration (79). Despite the good reliability of the GT1M, the authors noted that variation was increased at low levels of acceleration and suggest that this poses concern for using these accelerometers to measure sedentary behavior and to determine non-wear time (79).

Validity of the ActiGraph GT1M can be assessed in several ways. A systematic review identified eleven studies examining the validity of the ActiGraph GT1M in reference to energy expenditure (80). This review suggests that the ActiGraph GT1M in general demonstrated high validity that was as good as or better than the pooled triaxial and multisensor estimates ($r \geq 0.7$ compared with estimates from indirect calorimetry and doubly labelled water techniques). Important for this research is validity in relation to number of minutes spent in varying intensities of PA. Typically, recorded accelerometer counts are used to classify the PA in a given time segment into varying intensities of PA. Generally this is done by developing equations from calibration studies in which participants complete lab protocols based on some combination of walking, running, and lifestyle activities (81). In these studies, prediction equations or cut-points are developed to describe the relationship between measured oxygen consumption and PA counts or steps measured through accelerometry (81). Unfortunately, numerous cut-points exist and cut-point choice can substantially influence results (81). For example, Loprinzi et al. used NHANES data to examine the percent of adults meeting PA recommendations using 12 different published cut-points (82). Results ranged from 4.7% to 97.6%, a spread so wide as to be uninformative (82). Similarly, Evenson et al. examined the impact of cut-point choice on mean minutes of MVPA among older adults (83). They found that mean minutes ranged from 10.8 minutes per day to 106.8 minutes per day depending on the cut point chosen (83). These studies suggest that choice of cut-point can drastically influence results, making it an extremely important study design decision. Two commonly used sets of cut-points are the NHANES cut-points (MVPA: ≥2020 counts/min; VPA: ≥5999 counts/min) based on walking/running protocols (15) and the Matthews' cut-point (MVPA: ≥760 counts/min) based on walking/running and lifestyle activity protocols (81). A recent study examined the validity of these cut-points for the ActiGraph GT1M as compared to indirect calorimetry in a free-living environment (84). The study found that the NHANES cut-point significantly underestimated minutes of MVPA during the six hour period (n=23.8 minutes) while the Matthews' cut-point overestimated minutes of MVPA (n=13.6 min, p>0.05) (84). The authors concluded that neither set of cut-points was better than the other overall (84). Therefore, this research uses both sets of cut-points to examine the impact of cut-point choice.

PA that occurs in bouts of ten minutes or more was considered in all stages of this research. Considering bouts allows this work to be comparable with the 2008 Physical Activity Guidelines for Americans (3) and the World Health Organization recommendations (85), which specify that PA should be of at least 10 minutes in duration to count towards meeting the weekly goal. There is evidence that short bouts of PA are effective in improving cardiovascular health, however the specific ten minute cut-point used in the guidelines is an arbitrary choice. Additionally, considering PA in bouts aided in coding locations of PA, as described below, and additionally decreased the size of the dataset to one that is manageable for manual coding.

Exposure Assessment

Geographic location of participants was tracked using a Qstarz BT-Q1000X portable GPS unit (weight, 65 g; dimensions, 72 x 46 x 20 mm) with Wide Area Augmentation System (WAAS) enabled to improve accuracy (75, 77). Participants were asked to wear GPS units concurrently with the ActiGraph GT1M accelerometers for three consecutive one-week periods.

In a comparison of GPS units, Rodríguez et al. compared the Qstarz BT-Q1000X with four other popular GPS units (86). Although the unit had variable signal acquisition time [mean (sd)=21.8 (26.3) seconds], battery life was excellent (39 hours). Importantly, the Qstarz ranked in the top two for all tests of accuracy in terms of mean distance from either a known point or a highly accurate concurrently used GPS as described below (86). Specifically, it had the highest overall accuracy in static validity tests as compared to a geodetic point [mean (sd) distance from point: 2.1 m (0.8)] (86). The authors indicate that half of the measured points had an error <2 m from the geodetic point and none were greater than 4 m from it (86). The Qstarz was the second most accurate GPS in tests of dynamic validity when comparing measured points to those obtained from a highly (<30 cm) accurate Trimble GeoXH GPS in open space and moderate density scenarios [mean difference (sd): 5.2 m (3.8), 8.2 m (19.5), respectively] (86). In the dynamic, high density urban scenario, the Qstarz was the most accurate GPS [mean difference (sd): 20.0 m (13.8) (86).

In a similar study, Duncan et al. examined the static validity of several GPS units, including the Qstarz BT-Q1000XT, a unit technically very similar to the Qstarz BT-Q1000X (87). Both units incorporate a MTK II chipset, which influences signal acquisition time, and use 66 channels, which influences accuracy (87), making the results of this study potentially useful for comparison. Duncan et al. report similar mean acquisition time (26.3 seconds) and battery life (39.8 hour) for the Qstarz BT-Q1000XT as Rodríguez et al. report for the QStarz BT-Q1000X (87). These signal acquisition and battery life measures were the best of the examined GPS models in their study (87). They also report that the Qstarz BT-Q1000XT yielded the highest accuracy across all location types (open sky, under beacon, residential, mixed use, under canopy, high rise) for mean distance from the known point (87). This Qstarz model resulted in the smallest overall mean error from the geodetic points [mean (sd): 12.1 m (19.6)] as well as the lowest circular error probability (5.0 m) (87). The circular error probability was defined as the radius of a circle centered on the geodetic point that contained 50% of the measured GPS points

(87). Although the Qstarz unit was superior to other models overall, all of the GPS units tested were inaccurate in the high-rise setting (mean error=59.2 m) (87). Despite this, the Qstarz unit was notably more accurate than other models in the obstructed canopy setting (50% of points <5 m from known point) (87), potentially indicating its superiority over other models in an urban setting.

Data Cleaning, Reduction, and Handling of Missing Data

For previous analyses, raw GPS and accelerometer data were transferred to SAS and GPS points with less than 1-minute epochs were removed. Overlapping data occurring due to participants exchanging monitors between weeks were removed (75). Accelerometer non-wear time was identified as 90 minutes of consecutive zero counts, allowing for up to two minutes of nonzero counts if the 30 minutes before and after the nonzero counts contain no positive counts, and counts for these minutes were set to missing (75, 88). Data from days exceeding the standard 21-day monitoring period were be removed. In order to account for missing accelerometer data, participant data for a specific day must meet a standard compliant wear day definition. Main analyses considered four 10-hour days as compliant accelerometer wear; however, sensitivity of results to standard wear day definitions of four or seven days and 7-12 hours were examined. The coding protocol introduced below and detailed in APPENDIX 1 provided guidance on identifying and removing motorized travel. Ten or more minute PA bouts were identified using both NHANES and Matthews' cut-points, allowing for up to 20% of the bout to fall below the threshold (15). All analyses were completed only using those PA points that occur within a bout of PA. GPS data was used to impute missing home addresses and recruitment years for the few participants missing this information. Effects of missing accelerometer data were minimized by using the compliant wear day definitions described above. Missing GPS points were imputed if possible following the procedures outlined in the coding protocol. This procedure involved examining the recorded point(s) before and after the missing point(s) within a bout to impute the location of the missing point, as has been done in other studies of PA involving GPS (16).

There were 5,255 total monitoring days, of which 4,353 (82.8%), 4,176 (79.5%), 3,940 (75.0%), 3,679 (70.0%), and 2,919 (55.5%) met the requirements for compliant wear days of 7, 8, 9, 10, or 12 hours respectively. Given the large drop between 10 and 12 hours and the prevalence of 10-hour wear days in the literature (89), the 10-hour cut point was used in the main analyses. Of the 248 enrolled participants, 238 provided data during three weeks of concurrent accelerometer and GPS monitoring, four provided data during two weeks, and six during one week (75). Table 4 displays the number of participants with differing lengths of monitoring after applying the compliant wear day definition. All of these combinations provided adequate sample size for Specific Aim III (Figure 1). Therefore, participants with compliant wear days were first used to complete Specific Aim III (determining the number of days needed to adequately capture usual locations of activity). Sensitivity to choice of compliant wear day definitions was examined. Those participants fulfilling the requirement determined by Specific Aim III were then used in a sensitivity analysis to complete Specific Aim I.

Power

In analyses that appropriately control for the correlation of PA locations by participant, power for Specific Aims I and II rely on the number of participants for detecting differences by participant characteristics. Given the limited number of participants in the study, particularly when stratifying by participant characteristics, power to detect differences was limited. Therefore, this research emphasizes use of these results for hypothesis generation and sample size calculations in future studies.

Specific Aim 3 involved estimation of the intraclass correlation coefficient (ICC) that was used to calculate the number of monitoring days needed to reliably estimate minutes of PA spent in various locations. Figure 1 displays the sample size needed to produce an ICC with ±0.1 precision for each potential number of monitoring days identified as the recommendation for wear-time. The available sample sizes of 162, 200, and 214 for 14, 10, and 7 days of monitoring were more than adequate to precisely and reliably estimate the ICC needed for the Spearman-Brown calculation (maximum needed sample sizes for 14, 10, and 7 days are 75, 66, and 61 participants; Figure 1).

Table 3. Sociodemographic Characteristics of 248 Participants Enrolled in the SOPARC GPS Sub-Study 2009-2011.

		N	%
Sex	Male	110	44.4
	Female	138	55.6
Age	18-35	119	48.0
	36-59	85	34.3
	60-85	44	17.7
Race/Ethnicity	Non-Hispanic White	124	50.0
	Non-Hispanic Black	65	26.2
	Hispanic	36	14.5
	Other	22	8.9
	Missing	1	0.4
Education	High School /GED or less	56	22.6
	Some college or vocational	56	22.6
	College	85	34.3
	Post college	51	20.6
BMI	Under or Normal Weight	90	36.3
	Overweight	77	31.0
	Obese	81	32.7
Recruitment City	Los Angeles, CA	52	21.0
	Albuquerque, NM	50	20.2
	Chapel Hill and Durham, NC	50	20.2
	Columbus, OH	54	21.8
	Philadelphia, PA	42	16.9
Recruitment Location	Household	48	19.4
	Park	198	79.8
	Missing	2	0.8
Recruitment Year	2009	94	37.9
	2010	148	59.7
	2011	4	1.6
	Missing	2	0.8

BMI, body mass index; CA, California; GED, General Educational Development; NM, New Mexico, NC, North Carolina; OH, Ohio; PA, Pennsylvania

Table 4. Number of Participants with Various Combinations of Compliant Wear Day Definitions and Required Numbers of Compliant Days of the 248 Participants Enrolled in the SOPARC GPS Study 2009-2011

	At least 7 12-hour compliant days	**At least 7 10-hour compliant days**	**At least 10 10-hour compliant days**	**At least 14 10-hour compliant days**	**At least 14 9-hour compliant days**
California	41	46	43	36	40
North Carolina	47	49	49	46	49
New Mexico	40	45	43	33	39
Ohio	28	37	33	22	26
Pennsylvania	32	37	32	25	28
Total	188	214	200	162	182

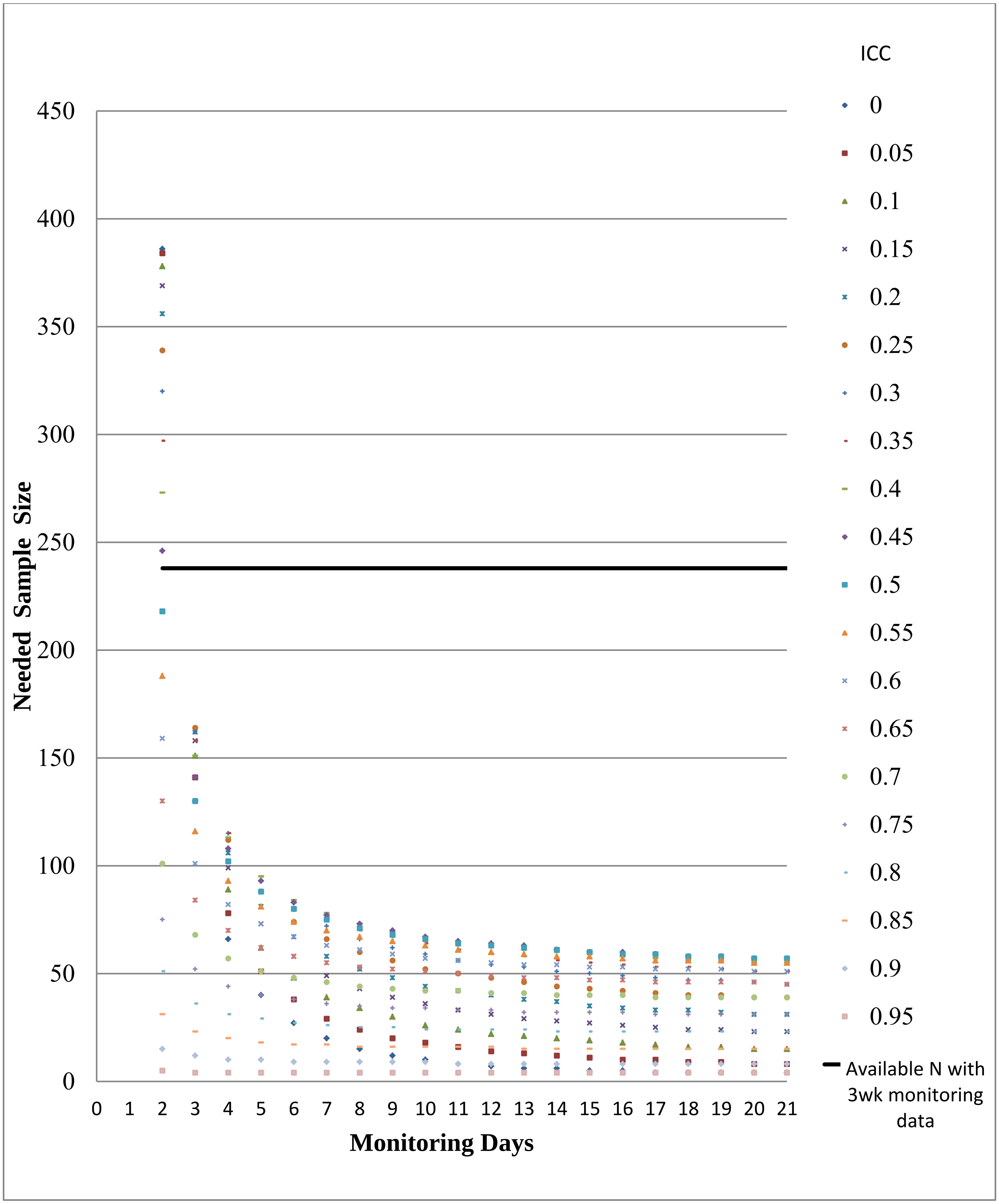


Figure 1. Sample Size Needed to Produce an ICC with ±0.1 Precision vs. Number of Monitoring Days

CHAPTER 5: WHERE ARE ADULTS ACTIVE? AN EXAMINATION OF PHYSICAL ACTIVITY LOCATIONS USING GPS IN FIVE UNITED STATES CITIES

Introduction

According to the World Health Organization (WHO), lack of physical activity (PA) is the fourth leading risk factor for mortality globally and accounts for significant disease burden (1). Despite the numerous benefits of PA, many individuals do not meet PA guidelines (3, 85). Over one-third of the world's population is insufficiently physically active, with proportions varying substantially between countries (90).

Given these trends, identifying factors that increase PA has become an important research focus. Researchers advocate use of theoretical frameworks when studying PA behaviors and developing health promotion programs (6, 7). These frameworks propose that a variety of factors, including individual, environmental, social, cultural, and policy, influence behavior (6, 7). Therefore, understanding the types of locations typically used for PA by some populations and potentially under-used by others may be important for developing targeted interventions to increase PA in underactive populations. Traditional methods of PA measurement fail to describe the context in which PA occurs (10, 11, 16), leading many to suggest Global Positioning System (GPS) technology as an important means of understanding PA locational contexts (16, 18).

Despite these recommendations, few studies have examined the places in which individuals are physically active, particularly for adults. The majority of existing studies of adults have been in the United States (US) or Australia, and those within the US have been limited in geographic scope (21-43). Indeed, only two were nationally generalizable in the US, and they either are dated (22) or only classified 60% of PA into specific locations, leaving the other 40% aggregated into an "other" category (29). In addition, several key methodologic issues are apparent in the literature, including a focus on leisure time PA as opposed to total PA (21, 23, 25-27, 29, 32, 37, 39) and use of self-report PA questionnaires instead of objective measures (21-27, 29, 32, 34, 35, 37-43), with many studies soliciting a binary yes/no response in regards to use of a particular location type for PA instead of percent of PA time completed at the location (21-24, 26, 27, 32, 35, 38-43). Studies that have used a GPS to aid in location assessment have typically lacked specificity in regards to location types, for example by simply reporting inside/outside the home neighborhood (28, 31).

In general, GPS or combined GPS and self-report measures have been more commonly used to assess PA locations in studies of children whereas self-report methods alone have been more prevalent with adults. For adults, studies that report specific types of locations have generally used self-report methods whereas those focusing on general locations (inside vs outside home neighborhood) have more commonly used GPS to identify locations.

Therefore, a device-based study of specific PA locations of US adults from an expanded geographic scope is notably missing from the literature. This type of study would allow for examination of the locational context of total PA time as well as refinement of location categories to prevent a large "other" category as has been problematic in other large scale studies (29). This study designed a protocol to systematically classify GPS points into PA location types and then implemented it using data from 5 geographically distinct US cities to help to fill this gap.

Methods

Study Population

The System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study recruited participants from five communities: Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania. Recruitment occurred within six (seven for Los Angeles) key parks in each of the communities (n=198, 80%) as well as from residences located within one mile of these parks (n=48, 19%) (Table 5). Participants were ineligible if they were <18 years old, non-English speaking, or non-ambulatory. Participants were enrolled in the spring, summer, and fall from May 2009 to April 2011, with most enrolled in 2009 (n=94) and 2010 (n=148) and only 4 enrolled in 2011.

SOPARC conducted sampling so as to recruit individuals of diverse sociodemographic characteristics (e.g. within the specific age and sex categories in Table 5). These characteristics (age, sex, race/ethnicity, and highest level of education achieved) were collected through a questionnaire. Study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height of participants at enrollment, respectively, allowing computation of body mass index (BMI in kg/m^2). Further participant recruitment and study details are available elsewhere (75-77).

Physical Activity Assessment

Participants were asked to concurrently wear an accelerometer and a GPS for three consecutive 1-week periods, both of which collected minute by minute timestamped data. Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip (75) to measure acceleration in the vertical plane (78). The accelerometer recorded activity in 1-minute epochs and has been shown to have high validity (80). Accelerometer non-wear time was identified as 90 minutes of consecutive zero counts, allowing for up to two minutes of nonzero counts if the 30 minutes before and after the nonzero counts contained no positive counts, and records for these minutes were flagged as non-wear (88). The GPS data were then merged with the accelerometer data, including the accelerometer minutes flagged as non-wear, by timestamp.

PA bouts were defined as ten or more minutes of accelerometer counts occurring above a given cut-point, allowing for 20% of the minutes to fall below the cut-point. In addition, a bout had to begin and end with a physically active minute and could not contain more than four consecutive minutes below the cut-point. We only examined PA in bouts of at least ten minutes as recommended by the 2008 Physical Activity Guidelines for Americans and the WHO (3, 85). The accelerometer count cut-point used can influence results (81-83), therefore sensitivity analyses were conducted using common cut-points. The chosen cut-points were the Matthews' cut-point (moderate to vigorous PA (MVPA): ≥760 counts/min) (81) and the NHANES cut-points (MVPA: ≥2020 counts/min; vigorous PA (VPA): ≥5999 counts/min) (15). Although the Matthews' MVPA cut-point is notably lower than the NHANES MVPA and VPA cut-points, the two methods have comparable validity (84). The main analysis considered wearing the accelerometer for at least four, ten-hour days as compliant. However, compliant monitoring time recommendations for GPS are lacking. Some have suggested that GPS monitoring may need to be longer to reliably estimate locations of PA (58) and recent estimations in this SOPARC population suggest GPS wear time may need to be near 12 days to reliably estimate locations of PA in parks and on roads and even longer for homes (91). Therefore, a sensitivity analysis also considered twelve 10-hour days as compliant.

Location Assessment

Participants wore a Qstarz BT-Q1000X portable GPS unit (weight, 65 grams; dimensions, 72 x 46 x 20 millimeter) to record geographic locations. The GPS units had Wide Area Augmentation System (WAAS) enabled to improve accuracy and points with less than a 1-minute epoch were removed (75, 77). The Qstarz BT-Q1000X consistently scored well for accuracy in comparison with four other popular GPS units, having superior static and dynamic validity in a variety of settings, including high density urban settings (86). Using a GPS with high performance in terms of validity was important for coding the latitude and longitude points into PA location types.

A protocol capable of classifying GPS points into PA location types in diverse settings was first developed (APPENDIX 1). The protocol was piloted on a small subset of data by multiple coders to qualitatively examine reliability and improve clarity. Protocol changes included the addition of location categories to be coded, clarification of the process of examining all of the points in a PA bout when making coding decisions, and clarification of rules for identifying points involved in motorized travel. The final protocol was implemented by a single author (KMH). Google Fusion Tables (Google Inc., Mountain View, CA) was used to map PA bouts within 35 miles of the participant's home address, resulting in a study area of approximately 19,000 mi^2 distributed across the five cities.

The protocol incorporated Google Maps (Google Inc., Mountain View, CA) features like satellite and street view into the coding process. GPS points were categorized into a variety of mutually exclusive PA location types using a standardized protocol based on visual inspection of Google imagery (APPENDIX 1). PA location categories included participant homes, roads, parks, commercial locations (e.g. large and small stand-alone retail locations, strip malls, malls, dense commercial districts, restaurants, and gas stations), schools (including pre-K to university), fitness locations (e.g. pay gyms and miscellaneous fitness areas (e.g. private tennis/soccer facilities, swim clubs, dance/martial arts studios)), footpaths/trails, and residential locations (excluding the participant's home). The remaining location types were collapsed into an "other" category due to low frequency; however these locations were coded as: services (banks, hotels, post offices, healthcare facilities, libraries), offices, golf courses, factories, churches, and entertainment (non-fitness oriented; e.g. museums, zoos). Points located in dense downtown areas that were too difficult to classify were coded as "downtown" and grouped with "other." The protocol instructed coders to consider of the overall pattern of points within a PA bout when making coding decisions, but did not require all points within the same PA bout to receive the same code. For example, if a participant walked to a park and then was active in the park, he or she could have minutes classified as road and park within the same bout. The protocol also described how to use the historical street view option to locate Google imagery recorded nearest in time to when the PA bout occurred. The protocol directed coders to use GPS speed and GPS points to identify and reclassify motorized travel as inactive minutes when necessary. Participant home addresses (all sites) and work addresses (subset of Pennsylvania participants) were geocoded. Further, the home addresses were mapped along with nighttime GPS data to impute missing home addresses and validate the geocoded addresses, similar to previous studies (92). Finally, because GPS accuracy is often limited indoors, particularly within large buildings, the protocol allowed for imputation of missing GPS points, in some cases, by examining the recorded point(s) before and after the missing point(s), as has been done in other studies of PA involving GPS [15]. This protocol was approved by the *Institutional Review Board of the University of North Carolina.*

Statistical Analysis

In order to compare location use across sociodemographic groups known to participate in widely different amounts of PA (e.g. older adults vs younger adults), the percent of PA bout time spent in each location type was calculated overall and by sociodemographic and recruitment characteristics for all three levels of PA intensity (Matthews' and NHANES MVPA, NHANES VPA). Sociodemographic characteristics examined include gender, age category, race/ethnic category, level of education, and BMI. Recruitment characteristics examined include recruitment state and recruitment site (park versus household). Differences by sociodemographic and recruitment characteristics were examined using Cochran-Mantel-Haenzel tests for general association. Results are focused on three location types (homes, roads, and parks) that may be most appropriate for intervention targeting.

Results

A total of 248 individuals were enrolled in the study, of whom 13 were excluded due to missing data (two contributed no accelerometer data and eleven had all missing data for GPS points) leaving 235 participants. Of these 235 participants, 224 had at least four ten-hour days of compliant accelerometer wear and 223, 192, and 47 completed bouts of Matthews' MVPA, NHANES MVPA, or NHANES VPA, respectively, on days with at least ten hours/day of wear (Table 5).

Participant Sociodemographic Characteristics

In general, more females than males participated and most were recruited from parks as opposed to households (79% vs 21% for those with Matthews' MVPA bouts) (Table 5). Although most participants were younger, white, and college educated, other groups were also represented (36% aged 36-59, 18% aged 60-85, 23% non-Hispanic black, 16% Hispanic, 9%

other race/ethnic groups, 22% with high school education/GED or less, and 22% some college or vocational school for those with Matthews' MVPA bouts; Table 5). Participants were evenly distributed among categories of BMI for those with Matthews' MPVA bouts. Patterns of sociodemographic characteristics were similar across enrolled participants and those with Matthews' and NHANES MVPA; however those with NHANES VPA bouts were more educated (p=0.01), had a lower BMI category (p=0.05), and were more likely to be recruited from North Carolina (p=0.02) as compared with those having Matthews' MVPA bouts (Table 5).

Time Spent in Physical Activity Intensities

The amount of time participants were physically active in bouts varied greatly by PA intensity (Table 6). Overall, 223 participants (99.6% of those with compliant wear) contributed 145,229 minutes in Matthews' MVPA bouts, 192 (85.7% of those with compliant wear) contributed 46,499 minutes in NHANES MVPA bouts, and 47 (21.0% of those with compliant wear) contributed 5,293 minutes in NHANES VPA bouts on days with at least 10 hours of accelerometer wear over the three weeks of monitoring (Table 6). Matthews' MVPA bouts ranged from 10 to 197 minutes with a median duration of 16 minutes, NHANES MVPA bouts ranged from 10 to 147 minutes with a median duration of 20 minutes, and VPA bouts ranged from 10 to 112 minutes with a median duration of 26 minutes.

Physical Activity Locations

The most common location for PA varied by intensity (Table 6). The most common location for PA in Matthews' MVPA bouts, with the lowest cut-point for MVPA, was the participant's home (29.4% of bout minutes) whereas roads were most common for the higher cut-point NHANES MVPA (27.6% of bout minutes) and NHANES VPA (23.6% of bout minutes) (Table 6). Together, homes and roads accounted for over 40% of bout-based PA minutes across all intensities (Matthews' and NHANES MVPA and NHANES VPA). Fitness facilities and schools were also important locations for NHANES VPA bouts (19.3% and 12.0% of VPA bout minutes, respectively) (Table 6). Parks were the locations for 13.4% of Matthews' MVPA bout minutes and 12.5% of NHANES MVPA bout minutes but only 4.3% of NHANES VPA bout minutes (Table 6).

PA Locations by Participant Sociodemographic and Study Characteristics

Cochran-Mantel-Haenzel analyses suggested a general association between PA location types (shown in Table 6) and all sociodemographic and recruitment characteristics (sex, age, race, education, BMI, recruitment state, recruitment location) for each intensity of PA (p<0.0001). However, the number of participants and/or minutes was low for VPA in many stratified analyses (Table 5).

PA in Participant Homes

The participant's home was a common location for PA of all intensities, but usage differed by sociodemographic and recruitment characteristics (Table 6, Table 7). For the lower cut-point Matthews' MVPA, homes were used for more bout minutes by females and participants recruited from New Mexico and Ohio (Table 7). Females completed 35.0% of their Matthews' MVPA bout minutes at home whereas males completed 23.3% (Table 7, Figure 2, Table 8). Participants recruited from New Mexico and Ohio had over one third of their Matthews' MVPA bout minutes at home whereas participants recruited from California and Pennsylvania had only 18.7% and 23.3%, respectively (Table 7, Figure 7, Table 13).

For the higher cut-point NHANES MVPA, homes were most used by Hispanics, those with less education, overweight or obese participants, and those recruited from New Mexico and Ohio (Table 7). Hispanics spent 29.1% of NHANES MVPA bout minutes in the home versus

18.8% for Non-Hispanic Whites (Table 7, Figure 4, Table 10). Participants with less education had more NHANES MVPA at home than those with higher education (28.3% high school education or less, 28.5% some college, 17.6% college degree) (Table 7, Figure 5, Table 11). Overweight and obese participants had over a fourth of their NHANES VPA bout minutes at the home whereas normal weight individuals had only 13.4% at home (Table 7, Figure 6, Table 12). The home was again an important location for those recruited from New Mexico (50.5%) and Ohio (37.0%) as compared with those recruited from California (2.9%) or North Carolina (11.8%) (Table 7, Figure 7, Table 13).

Homes were used most for the highest cut-point NHANES VPA by males and overweight participants. Patterns differed from those observed for Matthews' MVPA for gender in that males had more bout minutes at home (27.0%) than females (9.4%) (Figure 2, Table 8). Overweight participants (25.5%) had more NHANES VPA at home than did healthy weight participants (6.4%) (Table 12, Figure 6).

<u>PA on Roads</u>

Roads were commonly used for PA of all intensities, particularly for higher cut-point NHANES MVPA and VPA (Table 6). For the lowest cut-point Matthews' MVPA, roads were most used by older adults and participants recruited from California (Table 7). Older adults, aged 60-85, spent 21.1% of their Matthews' MVPA bout minutes on roads versus 14.5% for those aged 18-35 and 12.7% for those aged 36-59 (Table 7, Figure 3, Table 9). Participants recruited from California spent 36% of their Matthews' MVPA on roads whereas participants from all other recruitment states had 13% or less of their Matthews' MVPA bout minutes in this location (Table 7, Figure 7, Table 13).

For NHANES MVPA, roads were again important for older adults and participants recruited from California and additionally for those with higher education (Table 7). Over forty percent of NHANES MVPA bout minutes were on roads for those aged 60-85 years whereas this location accounted for only 23.2% and 25.7% of NHANES MVPA bout minutes for 18-35 and 36-59 year olds, respectively (Table 7, Figure 3, Table 9). Participants recruited from California spent 61% of their NHANES MVPA bout minutes on roads, those recruited from North Carolina 25%, and participants recruited in other locations less than 12% (Table 7, Figure 7, Table 13). Participants with a college or post-graduate degree had more NHANES MVPA bout minutes on roads (30.9%) than those with less education (16.6% high school education or less, 19.1% some college or vocational) (Table 7, Figure 5, Table 11).

Females and those with higher education as well as healthy weight and overweight individuals frequently used roads for the highest cut-point NHANES VPA. Females spent 31.8% of their NHANES VPA bout minutes on roads versus 14.8% for males (Figure 2, Table 8). Those with a college or post-graduate education spent 29.4% of NHANES VPA bout minutes on roads, those with a healthy weight 29.6% of minutes, and overweight individuals 24.2% (Tables 11/12, Figures 5/6). However, there are few individuals with NHANES VPA who have less than a college education or who are obese.

PA in Parks

Parks contributed to Matthews' and NHANES MVPA more than NHANES VPA (Table 6). For bout minutes in the lowest cut-point Matthews' MVPA, all race/ethnic groups had similar patterns of park use (Non-Hispanic Black 14.6%, Hispanic 12.6%, Non-Hispanic White 13.8%, Other 9.9%) (Table 7, Figure 4, Table 10). Parks were important for Matthews' MVPA for older adults, participants recruited in the three most southerly states, and healthy and overweight participants (Table 7). Park use increased with age (9.2% ages 18-35, 15.2% ages 36-59, 18.8% ages 60-85) (Table 7, Figure 3, Table 9). The distribution of Matthews' MVPA bout minutes in parks was similar across those recruited from California, North Carolina, and New Mexico (16.4%, 16.0%, 19.1%), but less for those recruited from Ohio and Pennsylvania (4.5% and 4.6%) even though monitoring was not completed during winter months in an attempt to control for seasonality (Table 7, Figure 7, Table 13). Healthy and overweight participants had more Matthews' MVPA bout minutes in parks than obese participants (17.7%, 13.7%, and 4.1%, respectively) (Table 7, Figure 6, Table 12). Matthews' MVPA park use was slightly higher among those recruited from parks (13.9% of bout minutes) as compared with those recruited from houses (6.5% of bout minutes) (Table 7, Figure 8, Table 14).

Males, Hispanics, those with the least education, healthy and overweight participants as well as those recruited from California and North Carolina used parks for more of their NHANES MVPA bout minutes (Table 7). Males completed 16.5% of their NHANES MVPA bout minutes in parks versus 8.6% for females (Table 7, Figure 2, Table 8). Hispanics completed 22.6% of their NHANES MVPA in parks while other race/ethnic groups had 12% or less there (Table 7, Figure 4, Table 10). Those with a high school education or less had NHANES MVPA bout minutes in parks (22.5% of bout minutes) more often than more highly educated groups (6.1% for those with some college and 11.6% for those with college degree) (Table 7, Figure 5, Table 11). In addition, 12.6% of NHANES MVPA bout minutes were in parks for those recruited from parks versus a similar 11.9% for those recruited from nearby households (Table 7, Figure 8, Table 14).

At the highest cut-point NHANES VPA, males and overweight individuals had more of their bout minutes in parks than their female and healthy weight counterparts. Males had 7.5%

of their NHANES VPA bout minutes in parks and overweight participants 10.7% versus <2% for both females and overweight participants (Tables 8/12, Figures 2/6).

Sensitivity analyses restricting to only those participants with at least twelve 10-hour days of wear reduced sample sizes, particularly for Matthews' and NHANES MVPA. However, this change showed little effect on the distribution of PA bout time across the various locations (Table 15).

Discussion

This study provides evidence that adult PA locations varied by PA intensity as well as participant sociodemographic and geographic characteristics. Using a newly developed coding protocol to assess location, these patterns of PA location use can inform targeted intervention development, both by identifying locations typically used by some populations and potentially under-used by others. While several PA location types were identified, participant homes, roads, and parks were common PA locations for which individually- and community-targeted interventions are possible. These locations may therefore benefit consideration when implementing Community Preventative Services Task Force (CPSTF) recommended PA interventions, which are based systematic reviews of the PA intervention literature. Importantly, some of the recommended CPSTF interventions are at the community level, increasing the potential population level effects on PA.

The CPSTF recommends individually-adapted health behavior change programs to increase PA in the community. These programs aim to assist individuals with incorporating PA into the daily routine, so they may be especially beneficial for groups like overweight/obese individuals, Hispanics, and those with lower education who appear to gain much of their PA from the home environment. Due to social pressures, overweight and obese individuals may be more comfortable undertaking higher cut-point MVPA at home (92). Likewise, groups that experience health disparities like Hispanics and those with lower educational levels may have less access or less time to participate in PA outside the home environment. At the same time, PA in the home was common for nearly all groups in comparison with other locations, which agrees with previous research on adults (17, 23, 25, 29, 34, 35, 37-43). Therefore, use of individually-adapted health behavior change programs focused on the home environment are likely to aid in increasing PA for a wide variety of individuals.

Another CPSTF recommended intervention focuses on community- and street-scale urban design and land use policies. This study, as with previous research on adults (26, 38, 40-43), demonstrated that roads and footpaths/trails are important locations for PA, particularly for higher cut-point NHANES MVPA and VPA. Thus, roads and footpaths/trails may be an important location for these urban design and land use policy interventions, such as those proposed by the National Complete Streets Coalition, especially in areas where road or footpath/trail use is low. For example, participants recruited from California in this study consistently used roads for far more of their PA than did participants from other states across all PA intensities. This suggests that factors such as the built environment or weather may make roads in the Los Angeles area more supportive of PA than in other sites, suggesting they may be a prime target for intervention in these areas where they are underutilized for PA.

The CPSTF also recommends social support interventions in community settings, which in part help individuals to develop social networks of PA partners. The results of this study suggest that these interventions could focus on creating walking or running groups for younger adults, those with less education, and obese individuals. These groups used roads for NHANES

MVPA half as much as their older, higher educated, and lower weight counterparts, suggesting roads may be an underutilized PA location for these groups.

Parks are often thought of as natural locations in which to focus community level PA interventions such as those described by the CPSTF. Although parks have often been identified as popular locations for adult PA (21-24, 26, 27, 32, 34-36, 38, 40-43), few studies have described park use as a proportion of total PA in different intensities (75). In this study, parks appeared to be more important for Matthews' MVPA and NHANES MVPA than VPA in this population. This suggests that CPSTF recommended interventions like social support interventions in community settings, community-wide campaigns, and creation of or enhanced access to places for PA combined with information outreach activities could focus on teaching community members ways to engage in VPA in parks. This could entail developing new park programming or better advertising current programming in the community.

This study demonstrates that some groups known to have low PA do use parks. For example, more Matthews' MVPA occurred in parks with increasing age and those with a high school education or less used parks more for NHANES MVPA than did other groups. Importantly, Matthews' MVPA park use was similar across race and education categories and Hispanics used parks for NHANES MVPA more than other groups, indicating the potential ability of parks to support PA without exacerbating existing health disparities. At the same time, obese individuals used parks less for MVPA than did their normal and overweight counterparts, indicating a potential group in need of CPSTF recommended interventions targeted at increasing their park use.

Geographically, park use was more prominent among participants recruited in the California, New Mexico, and North Carolina sites than the Ohio and Pennsylvania sites. This was an unexpected result given that attempts were made to control for season by restricting monitoring to the spring, summer, and fall. However, park use could differ due to weather within season or non-seasonal attributes of the sites such as park availability, quality, and safety across the sites, which are unaccounted for in this representation.

Limitations

There are several limitations to this study. Although this is a large sample of geographically- and sociodemographically-diverse participants among studies of physical activity, it is not a representative sample. This means that the results presented here based on socio-demographic or geographic characteristics may not be representative of these groups. Further, expected selection of those participating in VPA was observed, with most who undertook VPA being younger, white, highly educated, and non-obese. Therefore, in many cases stratified analyses must be viewed with caution due to the small number of participants represented in some categories.

Although Cochran-Mantel-Haenzel analyses suggested significant differences in PA location type among the various sociodemographic groups, another limitation is that multinomial modelling accounting for correlation of minute by minute PA location within participants was not possible due to the computational burden associated with modelling at the minute level. Additionally, although the coding protocol was implemented by a single coder to ensure consistency of interpretation of the coding protocol, examination of reliability across multiple coders was not possible.

This study used standard definitions of PA intensities, but a limitation of this choice is that the definition of VPA was not based on age or BMI, suggesting that the small number of seniors and obese individuals with VPA may be an underestimate of true VPA in these populations (90). In addition, accelerometers are known to capture only a proportion of PA; for example, they fail to capture swimming as the accelerometer model used in this study was not waterproof and may not record other kinds of PA accurately such as bicycling or weightlifting.

A final limitation of the study is that several participant characteristics correlated with recruitment state, making geographic and sociodemographic patterns difficult to disentangle, and two sites (Ohio and Pennsylvania) had lower GPS compliance, resulting in a substantial portion of missing data at these sites. Nevertheless, this remains a large study of diverse participants incorporating detailed examination of PA locations with a protocol that could be implemented within more representative populations.

Conclusion

Overall, this study provides a new coding protocol capable of more precisely classifying locations of PA than has been done in previous studies. Application of this protocol in a sociodemographically and geographically diverse adult population suggests that common locations of PA vary by PA intensity and participant sociodemographic and geographic characteristics. Homes, roads, and parks were discussed as potential PA locations when implementing CPSTF interventions. Each of these locations had sociodemographic- and geographic-specific use patterns that may be important when developing targeted interventions capable of increasing PA at the population level.

Table 5. Sociodemographic Characteristics of Participants in the SOPARC GPS Study 2009-2011

		Matthews' MVPA [a]		NHANES MVPA [b]		NHANES VPA [c]	
		N	%	N	%	N	%
Overall Number		223	-	192	-	47	-
Sex	Male	97	43.5	88	45.8	20	42.6
	Female	126	56.5	104	54.2	27	57.4
Age	18-35	102	45.7	91	47.4	27	57.5
	36-59	81	36.3	69	35.9	17	36.2
	60-85	40	17.9	32	16.7	3	6.4
Race/Ethnicity	Non-Hispanic White	113	50.7	104	54.2	31	66.0
	Non-Hispanic Black	52	23.3	37	19.3	7	14.9
	Hispanic	36	16.1	31	16.2	4	8.5
	Other	21	9.4	19	9.9	5	10.6
	Missing	1	0.4	1	0.5	0	-
Education	High School /GED or less	48	21.5	35	18.2	3	6.4
	Some college or vocational	49	22.0	39	20.3	7	14.9
	College or Post Grad	126	56.5	118	61.5	37	78.7
BMI	Under or Normal Weight	77	34.5	74	38.5	21	44.7
	Overweight	72	32.3	64	33.3	19	40.4
	Obese	74	33.2	54	28.1	7	14.9
Recruitment City	Los Angeles, CA	47	21.1	45	23.4	10	21.3
	Albuquerque, NM	47	21.1	39	20.3	5	10.6
	Chapel Hill and Durham, NC	49	22.0	48	25.0	21	44.7
	Columbus, OH	40	17.9	28	14.6	5	10.6
	Philadelphia, PA	40	17.9	32	16.7	6	12.8
Recruitment Location	Household	46	20.6	44	22.9	8	17.0
	Park	175	78.5	146	76.0	39	83.0
	Missing	2	0.9	2	1.0	0	-

BMI, body mass index; CA, California; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; NM, New Mexico; North Carolina ; OH, Ohio; PA, Pennsylvania; VPA, vigorous physical activity

[a] Those who engaged in MVPA bouts (Matthews' definition, ≥760 counts/min)

[b] Those who engaged in NHANES MVPA bouts (NHANES definition, ≥2020 counts/min)

[c] Those who engaged in NHANES VPA bouts (NHANES definition, ≥5999 counts/min)

Table 6. Total, Median per Participant, and Percent of Matthews' MVPA, NHANES MVPA, and NHANES VPA Bout Minutes Spent in Each Location Type among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

	Matthews' MVPA [a]			NHANES MVPA [b]			NHANES VPA [c]		
	Bout Minutes			Bout Minutes			Bout Minutes		
	Total	Median/ participant (IQR)	%	Total	Median/ participant (IQR)	%	Total	Median/ participant (IQR)	%
Home	42,735	116 (40, 242)	29.4	9,447	6 (0, 43)	20.3	994	0 (0, 0)	17.8
Road	21,885	25 (0, 105)	15.1	12,820	6 (0, 48)	27.6	1,250	0 (0, 0)	23.6
Park	19,465	11 (0, 72)	13.4	5,808	0 (0, 12)	12.5	227	0 (0, 0)	4.3
Commercial	12,375	14 (0, 42)	8.5	1,573	0 (0, 3)	3.4	206	0 (0, 0)	3.9
School	11,064	0 (0, 32)	7.6	4,242	0 (0, 0)	9.1	634	0 (0, 0)	12.0
Other	7,408	0 (0, 23)	5.1	1,665	0 (0, 0)	3.6	74	0 (0, 0)	1.4
Fitness	6,092	0 (0, 0)	4.2	3,565	0 (0, 0)	7.7	1,023	0 (0, 0)	19.3
Residential	5,053	0 (0, 17)	3.5	1,009	0 (0, 0)	2.2	112	0 (0, 0)	2.1
Footpath/Trail	2,016	0 (0, 1)	1.4	1,352	0 (0, 0)	2.9	478	0 (0, 0)	9.0
Motorized [d]	147	0 (0, 0)	0.1	75	0 (0, 0)	0.2	14	0 (0, 0)	0.3
Missing	16,989	5 (0, 59)	11.7	4,943	0 (0, 3)	10.6	331	0 (0, 0)	6.3
Total minutes	145,229			46,499			5,293		

IQR, interquartile range; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

[a] MVPA bout minutes defined by Matthews' definition (≥760 counts/min)

[b] MVPA bout minutes defined by NHANES definition (≥2020 counts/min)

[c] VPA bout minutes defined by NHANES definition (≥5999 counts/min)

[d] Motorized denotes minutes spent in short motorized travel during a PA bout (i.e. these minutes fell below the active threshold but were still part of a PA bout)

Table 7. Percent of MVPA Bout Minutes Spent in Three Location Types by Sociodemographic Characteristics of Participants in the SOPARC GPS Sub-Study, 2009-2011

		Matthews' MVPA [a]				NHANES MVPA [b]			
		Minutes	Home	Road	Park	Minutes	Home	Road	Park
Sex	Male	69,706	23.3	14.6	15.8	22,610	20.3	27.6	16.6
	Female	75,523	35.0	15.5	11.2	23,889	20.3	27.6	8.6
Age	18-35	60,699	26.7	14.5	9.2	22,920	19.3	23.2	12.7
	36-59	56,124	31.4	12.7	15.2	14,801	21.5	25.7	14.6
	60-85	28,406	31.3	21.1	18.8	8,778	21.1	42.3	8.4
Race/Ethnicity	NH White	84,745	30.9	16.5	13.8	27,604	18.8	30.7	11.2
	NH Black	25,671	27.6	8.3	14.6	6,945	22.5	16.9	12.0
	Hispanic	20,433	28.2	13.6	12.6	5,858	29.1	24.9	22.6
	Other	14,183	25.2	20.8	9.9	6,030	15.6	28.3	9.5
Education	≤ High School	24,265	32.3	11.3	12.0	6,366	28.3	16.6	22.5
	Some College or vocational	26,646	28.5	10.5	16.4	5,301	28.5	19.1	6.1
	College or Post Grad	94,318	28.9	17.3	12.9	34,832	17.6	30.9	11.6
BMI	Normal Weight	64,603	29.2	16.6	17.7	20,523	13.4	30.3	15.1
	Overweight	49,080	28.3	15.9	13.7	16,842	25.7	30.4	13.3
	Obese	31,546	31.7	10.8	4.1	9,134	25.9	16.3	5.2
City	Los Angeles, CA	32,532	18.7	36.0	16.4	12,644	2.9	60.8	20.6
	Albuquerque, NM	29,592	38.6	7.2	19.1	6,964	50.5	12.0	7.6
	Chapel Hill/Durham, NC	41,545	31.7	13.1	16.0	12,951	11.8	24.6	13.9
	Columbus, OH	18,993	35.6	2.9	4.3	6,103	37.0	2.8	6.2
	Philadelphia, PA	22,567	23.3	9.2	4.6	7,837	22.7	11.9	6.4
Recruitment	Household	24,886	28.5	20.7	6.5	8,354	18.1	34.9	11.9
	Park	117,242	29.3	14.2	13.9	37,732	20.2	26.2	12.6

BMI, body mass index; CA, California; MVPA, moderate to vigorous physical activity; NH, Non-Hispanic; NHANES, National Health and Nutrition Examination Survey; NM, New Mexico; North Carolina ; OH, Ohio; PA, Pennsylvania

[a] Matthews' definition, ≥760 counts/min

[b] NHANES definition, ≥2020 counts/min

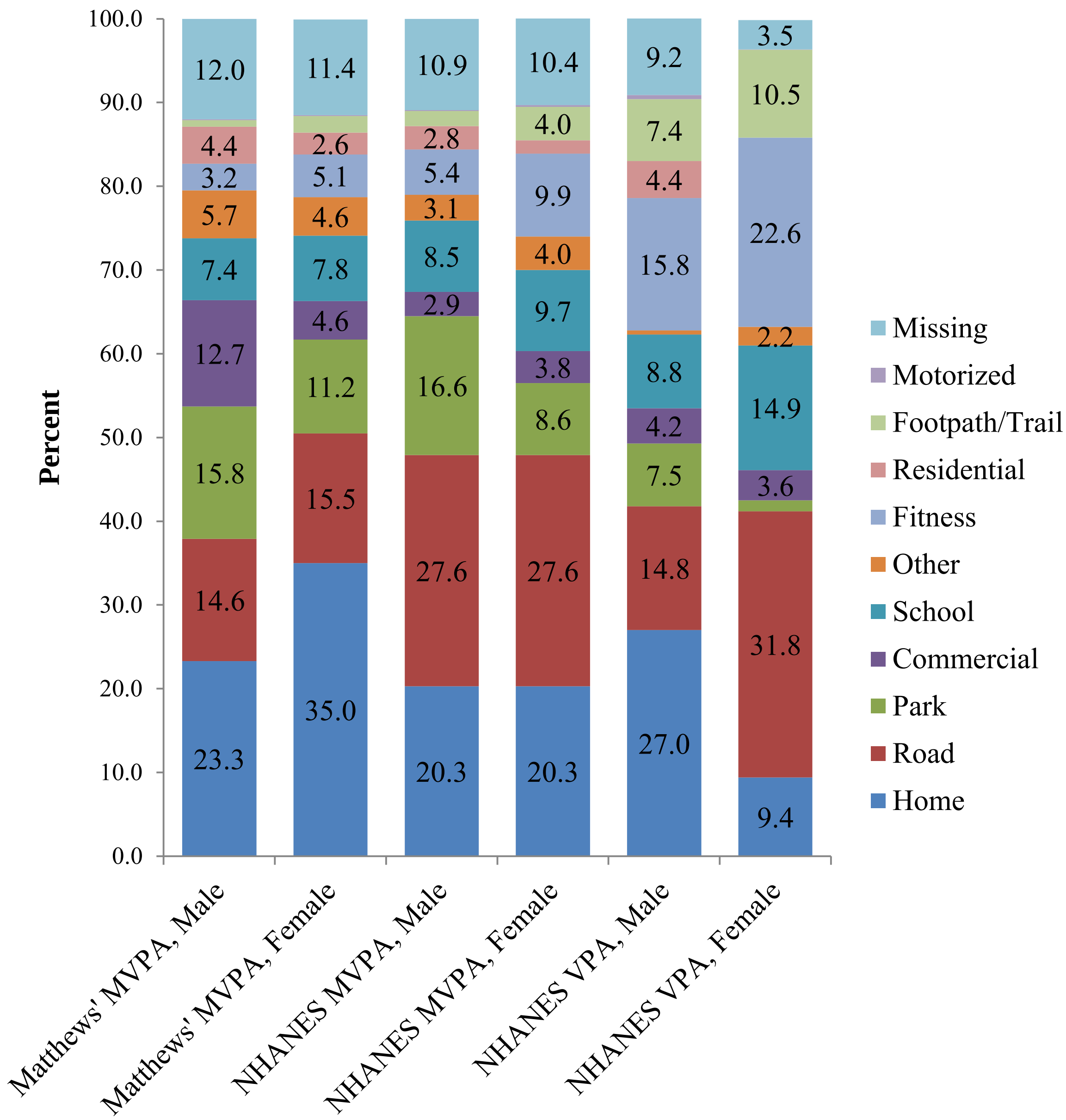


Figure 2. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Gender. Unlabeled proportions represent ≤2%

Table 8. Number of Participants and PA Minutes by PA Intensity and Gender among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Gender	Participants (N)	Minutes (N)
Matthews' MVPA	Male	97	69,706
	Female	126	75,523
NHANES MVPA	Male	88	22,610
	Female	104	23,889
NHANES VPA	Male	20	2,548
	Female	27	2,745

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

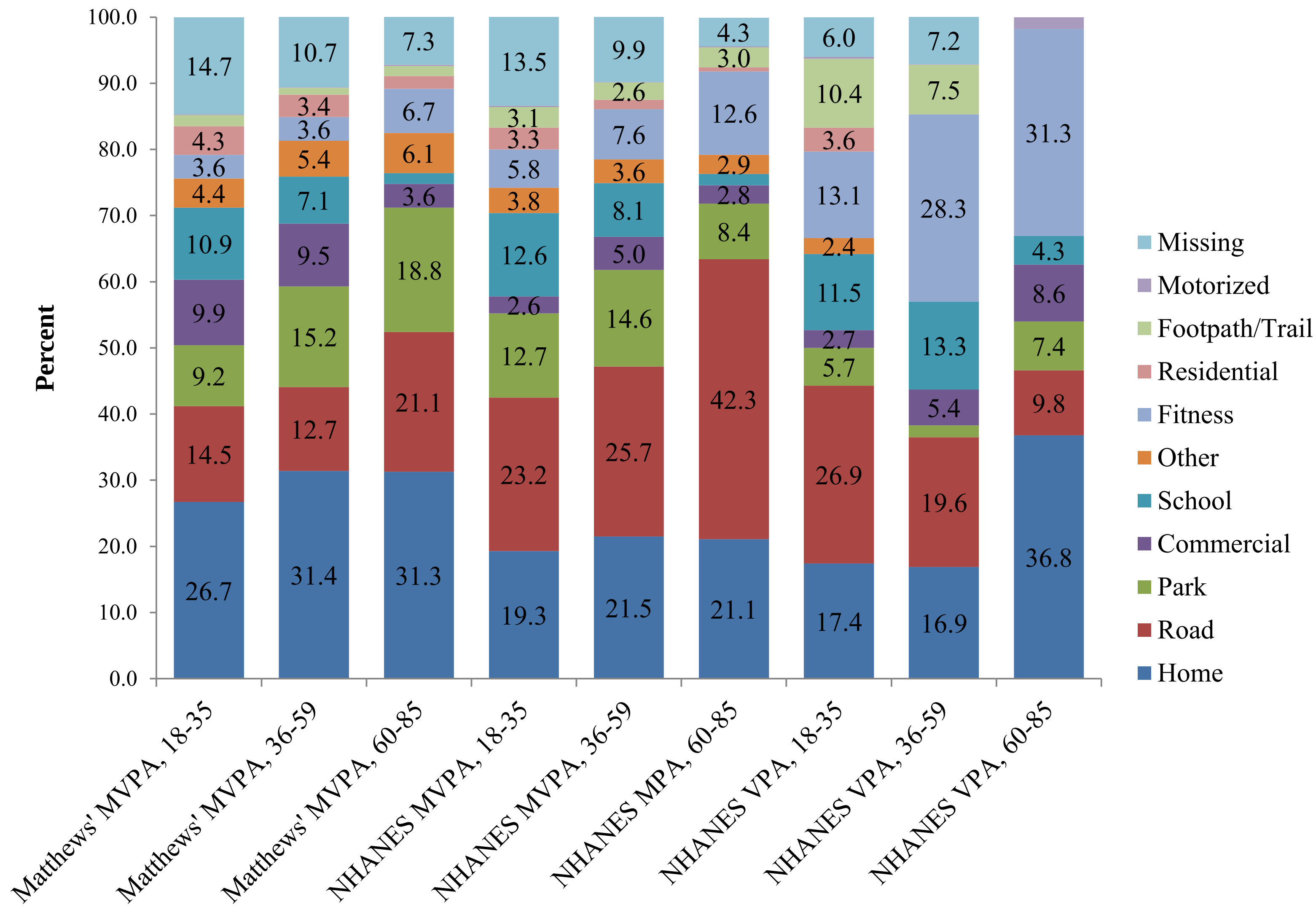


Figure 3. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Age. Unlabeled proportions represent ≤2%

Table 9. Number of Participants and PA Minutes by PA Intensity and Age among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Age	Participants (N)	Minutes (N)
Matthews' MVPA	18-35	102	60,699
	36-59	81	56,124
	60-85	40	28,406
NHANES MVPA	18-35	91	22,920
	36-59	69	14,801
	60-85	32	8,778
NHANES VPA	18-35	27	8,778
	36-59	17	1,977
	60-85	3	163

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

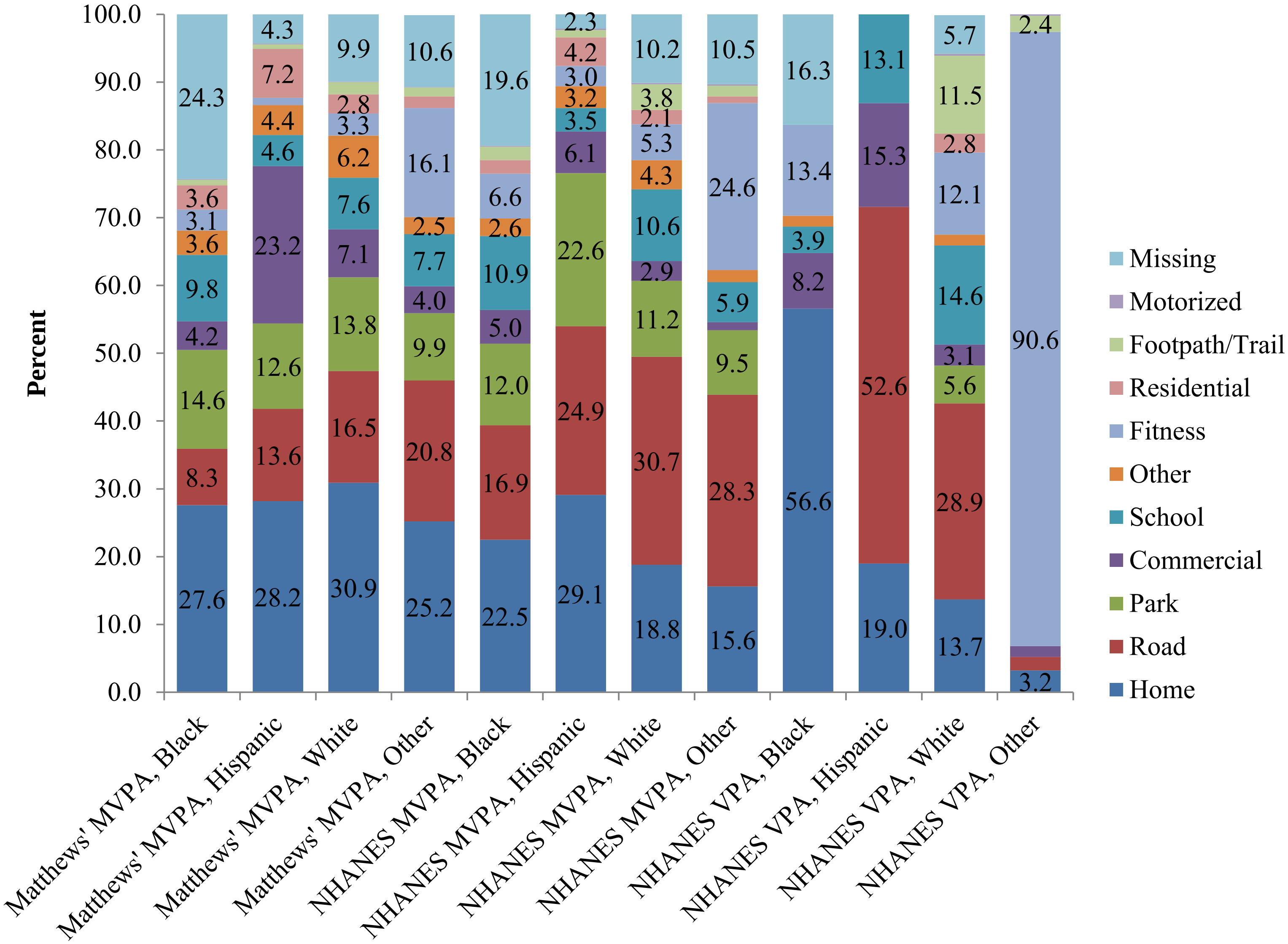


Figure 4. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Race/Ethnicity. Unlabeled proportions represent ≤2%

Table 10. Number of Participants and PA Minutes by PA Intensity and Race/Ethnicity among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Race/Ethnicity	Participants (N)	Minutes (N)
Matthews' MVPA	White	113	84,745
	Black	52	25,671
	Hispanic	36	20,433
	Other	21	14,183
NHANES MVPA	White	104	27,604
	Black	37	6,945
	Hispanic	31	5,858
	Other	19	6,030
NHANES VPA	White	31	4,043
	Black	7	613
	Hispanic	4	137
	Other	5	500

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

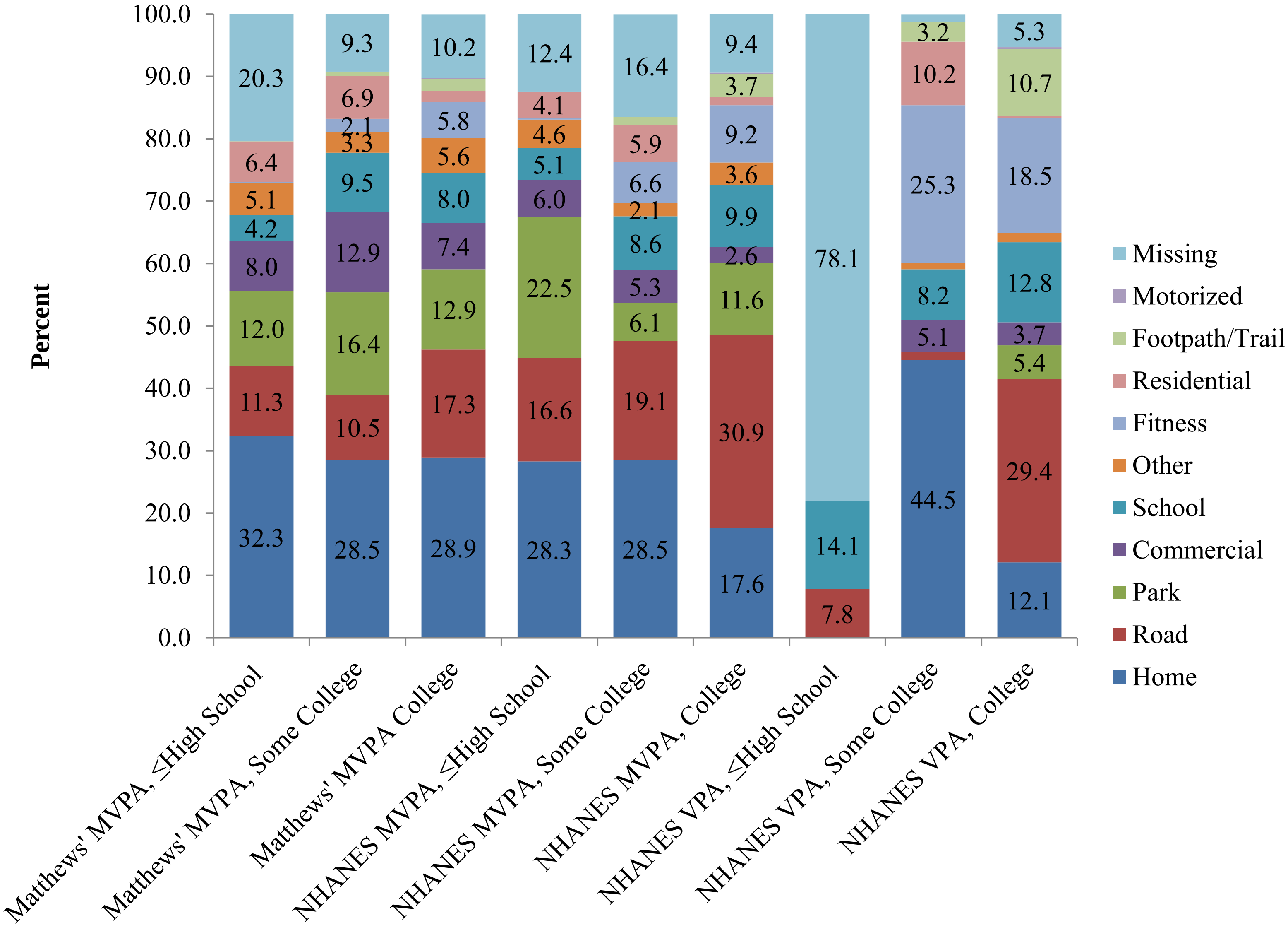


Figure 5. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Education. Unlabeled proportions represent ≤2%

Table 11. Number of Participants and PA Minutes by PA Intensity and Education among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Education	Participants (N)	Minutes (N)
Matthews' MVPA	≤HS	48	24,265
	Some College	49	26,646
	College	126	94,318
NHANES MVPA	≤HS	35	6,366
	Some College	39	5,301
	College	118	34,832
NHANES VPA	≤HS	3	128
	Some College	7	988
	College	37	4,177

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

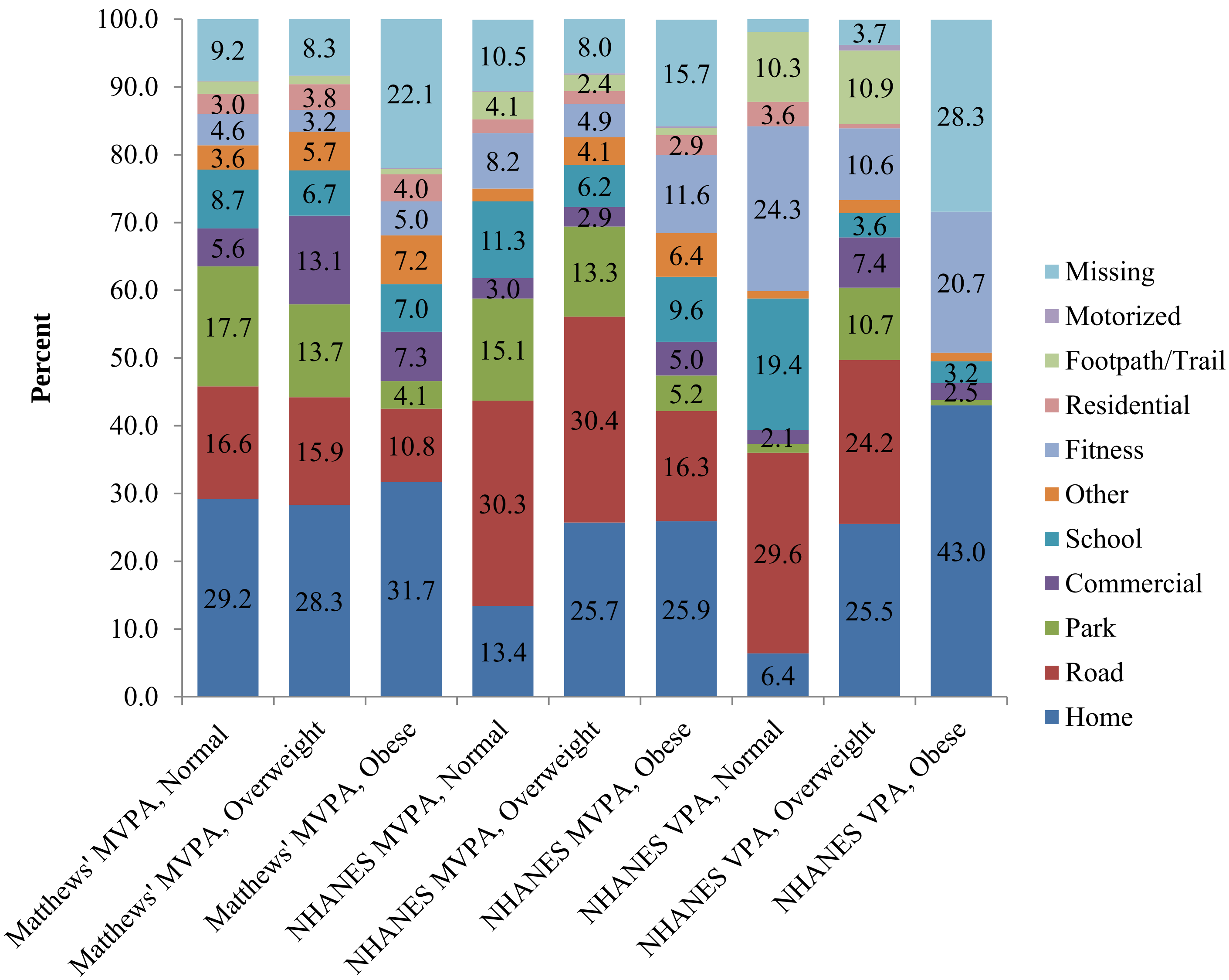


Figure 6. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and BMI Category. Unlabeled proportions represent ≤2%

Table 12. Number of Participants and PA Minutes by PA Intensity and Body Mass Index Category among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	BMI	Participants (N)	Minutes (N)
Matthews' MVPA	Normal	77	64,603
	Overweight	72	49,080
	Obese	74	31,546
NHANES MVPA	Normal	74	20,523
	Overweight	64	16,842
	Obese	54	9,134
NHANES VPA	Normal	21	2,815
	Overweight	19	1,729
	Obese	7	749

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

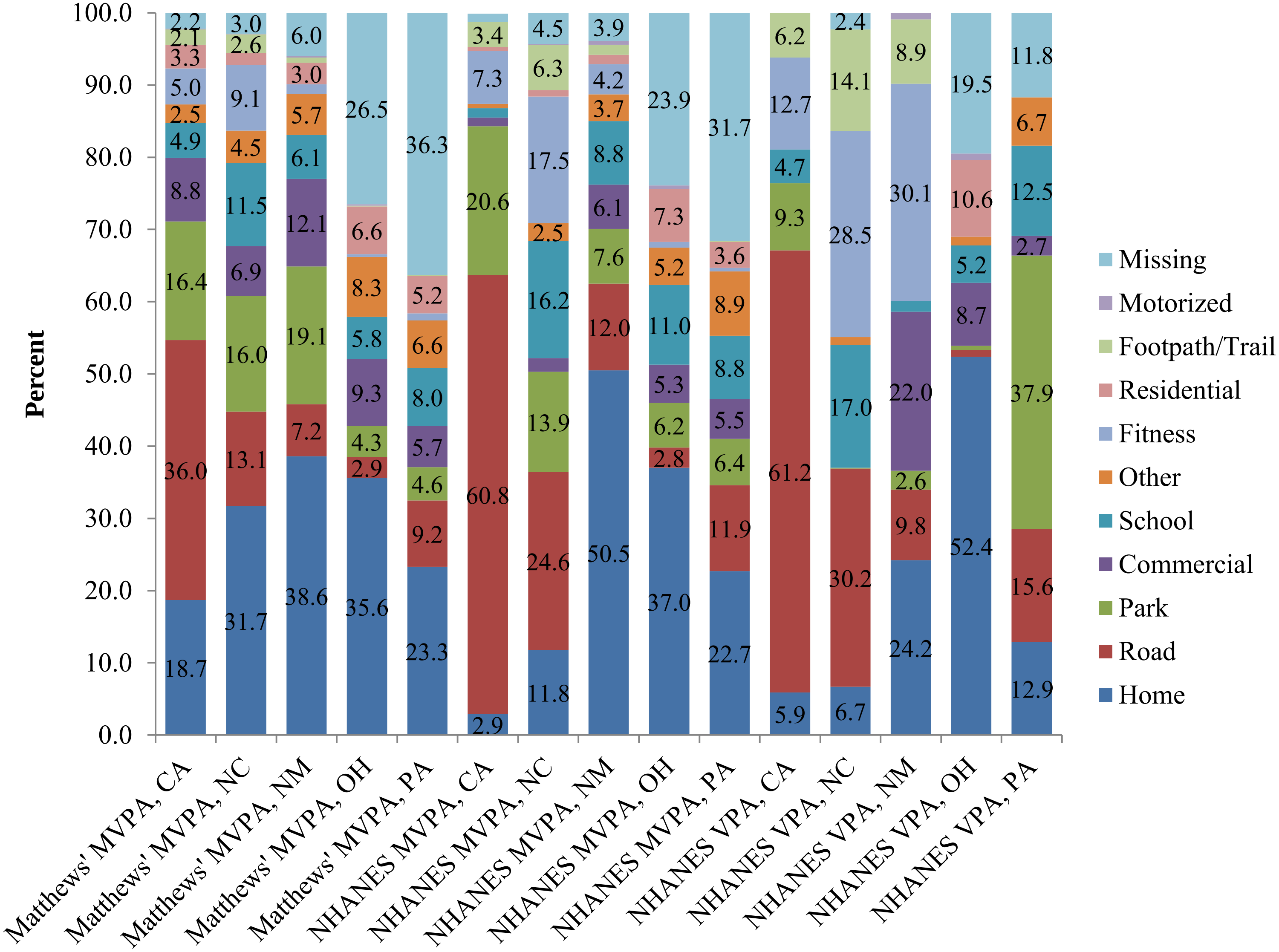


Figure 7. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Recruitment State. Unlabeled proportions represent ≤2%

Table 13. Number of Participants and PA Minutes by PA Intensity and Recruitment State among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Recruitment State	Participants (N)	Minutes (N)
Matthews' MVPA	CA	47	32,532
	NC	49	41,545
	NM	47	29,592
	OH	40	18,993
	PA	40	22,567
NHANES MVPA	CA	45	12,644
	NC	48	12,951
	NM	39	6,964
	OH	28	6,103
	PA	32	7,837
NHANES VPA	CA	10	387
	NC	21	2,938
	NM	5	459
	OH	5	1,060
	PA	6	449

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

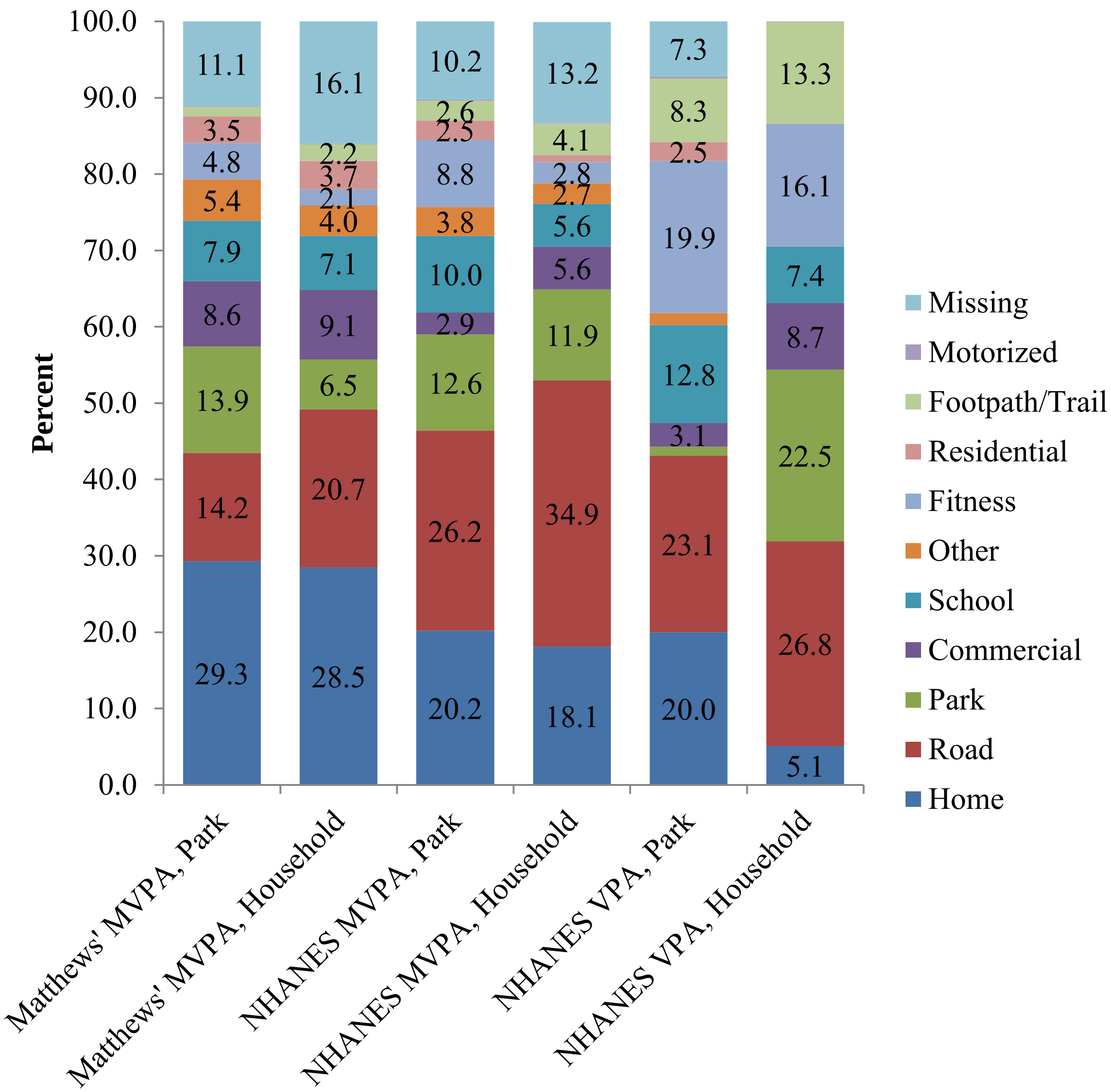


Figure 8. Percent of Physical Activity Bout Minutes in Each Location by Physical Activity Intensity and Recruitment Location. Unlabeled proportions represent ≤2%

Table 14. Number of Participants and PA Minutes by PA Intensity and Recruitment Location among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

Intensity	Recruitment Location	Participants (N)	Minutes (N)
Matthews' MVPA	Household	46	24,886
	Park	175	117,242
NHANES MVPA	Household	44	8,354
	Park	146	37,732
NHANES VPA	Household	8	760
	Park	39	4,533

MVPA, moderate to vigorous physical activity; N, number; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

Table 15. Percent of Matthews' MVPA, NHANES MPA, and NHANES VPA Bout Minutes Spent in Each Location Type Restricting to Those with at Least 12 10-Hour Days of Accelerometer Wear among SOPARC GPS Sub-Study Participants Over Three Weeks, 2009-2011

	Matthews' MVPA [a]	NHANES MVPA [b]	NHANES VPA [c]
Participants	186	167	46
Total minutes (n)	132,121	42, 757	5,257
Location			
Home (%)	29.4	20.3	17.7
Road (%)	14.6	27.4	23.8
Park (%)	13.4	13.1	4.3
Commercial (%)	8.8	3.4	3.5
School (%)	7.6	9.7	12.1
Other (%)	5.5	3.9	1.4
Fitness (%)	4.6	8.3	19.5
Residential (%)	3.2	2.0	2.1
Footpath/Trail (%)	1.5	3.2	9.1
Motorized [d] (%)	0.1	0.2	0.3
Missing (%)	10.3	8.6	6.3

MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

[a] MVPA bout minutes defined by Matthews' definition (≥760 counts/min)

[b] MVPA bout minutes defined by NHANES definition (≥2020 counts/min)

[c] VPA bout minutes defined by NHANES definition (≥5999 counts/min)

[d] Motorized denotes minutes spent in short motorized travel during a PA bout (i.e. these minutes fell below the active threshold but were still part of a PA bout)

CHAPTER 6: ARE RESIDENTIAL BUFFERS REPRESENTATIVE OF ADULT PHYSICAL ACTIVITY SPACE?

Introduction

Researchers often advocate use of theoretical frameworks, such as the Social Cognitive Theory and the Social Ecological Framework, when studying physical activity (PA) behaviors and developing health promotion programs (6, 7). These frameworks propose that a variety of factors, including individual, environmental, social, cultural, and policy, influence behavior (6, 7). The built environment is a factor suggested by these theoretical frameworks that is of particular interest for PA given its potential as an intervention target at the population level. It has been defined as encompassing urban design, land use, and the transportation system and considers the patterns of human activity within the physical environment (9). Thus, questions about attributes of the built environment that support PA are primary questions of interest in PA research.

Built environment exposures are often assigned using a participant's residential address, either by using an administrative boundary (e.g. zip code, census tract) or by creating a buffer around the residential address (e.g. a circular Euclidian distance-based buffer or a road network distance-based buffer) (19, 20, 31, 46-62). Indeed, a systematic review of the literature indicated that 90% of studies on the relationship between the contextual built environment and cardiometabolic risk factors focused solely on the residential environment (60).

This residential-based exposure assignment method is at odds with the concept of activity space, which represents the overall geographical area in which individuals spend time in their day-to-day lives (63, 64). Many authors have therefore been critical of the theory underlying use of residential-based demarcations, indicating that it allows for substantial misclassification of exposure leading to potential inconsistent or weak effects (10, 19, 20, 31, 46-59, 65). A review on the relationship between obesity-related outcomes and environmental correlates postulated that many of the inconsistencies observed in the literature were caused by methodological issues surrounding neighborhood definitions and the resulting derivation of environmental attributes (48). Further, residential-based exposure assignment methods have received criticism from both the geography and public health fields, being called, for example, “place-based” instead of “people-based” (61) and the “local” (53) or “residential” (46) “trap”, indicating their failure to measure exposures from the locations in which people actually spend time.

The main criticism of residential based demarcations is that they fail to align the spatial assessment of environmental attributes with the spatial assessment of health behaviors (10, 46, 54). Given these various criticisms, many authors have called for assignment of contextual exposures that better align with the spatial locations in which individuals spend time (10, 16, 18-20, 31, 47, 48, 52-58). Many have therefore suggested that GPS enabled devices could be used to more accurately measure these environmental contexts (16, 18, 20, 31, 47, 48, 50, 52, 55, 56, 58, 61, 62, 68). Despite this consensus, many researchers still use one of the residential based exposure assignment methods as studies involving GPS can be costly, time-intensive, and introduce advanced data management and manipulation challenges. Understanding the proportion of time spent in different health behaviors in these variously defined residential buffers is an important step in understanding the accuracy of these studies. Specifically, it will inform the validity of the assumption that the home neighborhood accurately represents built environment exposures encountered during PA and will subsequently provide guidance on whether or not weak effects seen in the literature are due to measurement error.

This study therefore 1) assessed both the percent of physical activity (PA) time spent within residential buffers 2) proposed two new definitions of PA space to represent the spatial areas in which individuals completed bouts of PA measured by GPS over a three-week period and 3) examined the degree of spatial overlap between these PA spaces and traditional residential-defined buffer. Further, differences by sociodemographic characteristics were examined given that these factors may affect how near to home one engages in PA. Previous research has suggested that factors such as gender and socioeconomic status may impact how far from home PA occurs, but this research was completed on a small population with limited sociodemographic diversity (69). These results can help researchers understand the potential impact of choosing the various residential-based buffer methods to assign contextual exposures and may indicate which, if any, of these methods accurately represent the PA spaces of individuals. Further, these methods could be followed to develop activity spaces specific to other health behaviors, such as the food or tobacco environments.

Methods

Study Population

This study used data collected as part of the System for Observing Play and Recreation in Communities (SOPARC) GPS sub-study. The initial data collection involved recruitment of participants from key parks within five communities (Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania) as well as from residences within one mile of the parks. Participants were eligible for the study if they were ≥18 years old, English-speaking, and ambulatory. Sociodemographic data (age, sex, race/ethnicity, and highest level of education achieved) were collected through a questionnaire. Study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height of participants at enrollment, respectively, allowing classification of body mass index (BMI, kg/m^2) into categories of normal weight (<25 kg/m^2), overweight (≥25 to <30 kg/m^2), or obese (≥30 kg/m^2).

Participants were asked to concurrently wear an accelerometer to measure PA and a GPS to measure location for three consecutive 1-week periods during the spring, summer, or fall of 2009-2011. Details of the accelerometer and GPS are discussed in detail below. Further participant recruitment and study details are available elsewhere (75-77). Study protocols were approved by appropriate study site affiliated institutional review boards and participants provided written informed consent.

Physical Activity Assessment

Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip for three consecutive 1-week periods (75). The accelerometer recorded PA in 1-minute epochs and has demonstrated validity (80). Accelerometer non-wear time was identified as 90 minutes of consecutive zero counts, allowing for up to two minutes of nonzero counts if the 30 minutes before and after the nonzero counts contain no positive counts (75, 88). Counts for these non-wear minutes were flagged as missing. The GPS data were then merged with the accelerometer data, including the accelerometer minutes flagged as non-wear, by timestamp.

Bouts of ten minutes or more of moderate to vigorous physical activity (MVPA) were used to conform with the 2008 Physical Activity Guidelines for Americans and the World Health Organization (3, 85). MVPA bouts were identified based on the Matthews' cut-point (MVPA ≥760 counts/min) (81), allowing for 20% of the minutes to fall below the cut-point. In addition, a bout had to begin and end with a physically active minute and could not contain more than four consecutive minutes below the cut-point. The analysis considered wearing the accelerometer for at least four, ten-hour days as compliant.

Physical Activity Location Monitoring

Geographic location of participants was tracked using a Qstarz BT-Q1000X portable GPS unit (weight, 65 grams; dimensions, 72 x 46 x 20 millimeters) with Wide Area Augmentation System (WAAS) enabled to improve accuracy (75, 77). GPS points were recorded in one minute epochs. Participants were asked to wear GPS units concurrently with the ActiGraph GT1M accelerometers for three consecutive one-week periods.

Residential Buffer Area Creation

Participant home addresses were used to define several residence-based buffers in ArcGIS 10.3.1 (ESRI 2015, Redlands, CA) that span those commonly used in the literature. Home addresses were first geocoded using the 2010 TIGER/Line shape files in ArcGIS 10 and unmatched addresses were geocoded with electronic maps as needed (75). Residence-based buffers were created with the geoprocessing buffer tool (0.5, 1, and 5 mile circular buffers, encompassing all area 0.5, 1, and 5 miles in Euclidian (straight-line) distance from the home address) and network analyst service areas (0.5, 1, and 5 mile road network buffers, encompassing all area 0.5, 1, and 5 miles in road network distance from the home address) (63).

Physical Activity Space Creation

MVPA GPS points that were part of a 10 minute or longer bout were used to create two new measures of PA space, an overall PA space and an independent PA bout-based PA space. These measures were derived from the general concept of activity space, which seeks to describe the space in which individuals conduct day-to-day activities regardless of physical activity level

(63, 64). Typically activity space is constructed by mapping all of the locations in which a person experiences time during the day. In these analyses, the measures have been adjusted to represent only the space in which individuals were physically active. Specifically, all MVPA GPS points that were part of a MVPA bout during the 3 weeks were used to create a single overall minimum convex polygon space for each participant (Figure 9). The minimum convex polygon (convex hull) is the smallest polygon containing all points. In addition to the overall minimum convex polygon, a PA space layer was created for each participant based on their independent MVPA bouts (Figure 10). In this case, instead of using all bout-based MVPA points to create a single, overall PA space for each participant, the minimum convex polygon tool in ArcGIS was used to create a space for each MVPA bout. These individual bout PA spaces were created in a single layer and dissolved by participant to use in comparison with the residential-based buffers described above. This bout-based method is proposed to potentially limit inclusion of large sections of unused areas between PA locations as could occur in creating overall PA spaces (Figures 9, 10) and is therefore thought to be more representative of the spatial areas in which participants engage in PA. This approach has been previously proposed for summarizing spatial data that is unevenly distributed (93). In all cases of PA space creation, the data were first cleaned to remove bouts that were unreasonably far (>35 miles) from the participant's home address. These represent bouts that are not likely part of routine behavior and were removed to prevent these outliers from influencing results.

<u>Geographic Analyses</u>

Results are presented in relation to both time and geography. First, the percent of total MVPA time actually occurring within the residential-based buffers was calculated based on the percent of 1-minute bout-based MVPA GPS points located within these areas. The number of a participant's MVPA minutes occurring within their specific residential-based buffers was derived by first completing a one to many spatial join of the residential buffer and MVPA point layers with the match intersect option in ArcGIS 10.3.1. Select by attribute was performed on the joined layer to identify records where a participant's MVPA point intersected their own residential buffer (as opposed to another participant's residential buffer) and the results of this selection were outputted. Finally, the frequency tool was used to create the summed minutes of MVPA for each person (since each GPS point represents one minute of MVPA). Results were exported to SAS 9.3 (Cary, NC) to calculate the percent of MVPA time spent in the residential buffers for each participant. Results are presented overall and by sociodemographic factors (gender, age, race, education), BMI, and state of recruitment, with differences examined by Kruskal Wallis tests.

Second, layers of residential-based buffers were overlaid with the overall and individual bout-based PA layers seen in example Figure 11. ArcGIS 10.3.1 was then used to calculate 1) the percent of land area in residential-based buffers used for MVPA (C/A in Figure 11) and 2) the percent of land area in PA spaces located within residential-based buffers (C/B in Figure 11). This was completed using the Tabulate Intersection tool with the participant ID used for the zone field and the class field. Select by attribute was again completed on the outputted intersection layer to identify only the area overlap between each participant's own residential buffers and their own PA spaces. For analyses based on individual bout-based PA spaces, the layers were first dissolved by participant ID to remove double-counting of area. These results are again displayed overall and by sociodemographic factors (age, gender, race, education), BMI, and state of recruitment, with differences examined by Kruskal Wallis tests.

The built environment may indirectly influence PA at home, where a large proportion of

PA occurs (94). For example, non-supportive built environments could result in reduced residential neighborhood PA and increased home PA. Yet, interest in the direct effects of the built environment on PA not occurring at the home is also of importance. Therefore, a sensitivity analysis was completed using only MVPA bout minutes that occurred away from the participant's home address. MVPA bout minutes at home were identified using a newly developed coding protocol described elsewhere (94). All analyses were completed separately by state to allow use of a site-appropriate projected coordinate system (North American Datum 1983 State Plane).

Results

The SOPARC GPS sub-study enrolled 248 participants of whom thirteen were excluded due to missing data (two who contributed no accelerometer data and eleven who had all missing data for GPS points), 12 were excluded due to non-compliant accelerometer wear (less than four 10-hour days), and 6 had home addresses that could not be geocoded, leaving 217 participants for analysis. The participants contributed a median 17 days of monitoring (interquartile range: 13-20). Participants included in the analysis had similar sociodemographic characteristics as those initially enrolled. Included participants ranged from 18-85 years of age [mean (SD): 41.0 (15.7)] and 45% were male (Table 16). Participants were from varied racial/ethnic (50% Non-Hispanic White, 24% Non-Hispanic Black, 16% Hispanic, 9% Other (Asian/Pacific Islander, Native American, or multi-racial)) and educational (22% ≤high school education, 22% some college or vocational school, 56% college or post graduate degree) backgrounds. BMI was evenly distributed, with 34% under or normal weight, 33% overweight, and 33% obese. The majority of Non-Hispanic Blacks were recruited in Ohio and Pennsylvania (63%) and Hispanics in New Mexico and California (74%). Most individuals with a post-graduate education were recruited from North Carolina (42%) and 66% of those with a high school education or less were recruited from Pennsylvania and Ohio.

Physical Activity Time Spent in Residential Buffers

The median percent of MVPA bout time spent within variously sized residential buffers ranged from 39%-74%, with higher median percentages in larger residential buffers, although participant variation occurred (Table 17). Median percent of MVPA bout time spent in residential buffers varied by sociodemographic characteristics (Table 18). For example, age (p=0.03) and recruitment state (p=0.02) were associated with MVPA bout time spent in 0.5 mile network buffers. Older adults and those recruited from New Mexico consistently spent more of their MVPA bout time in 0.5 mile residential buffers (e.g. median 45% vs 32% MVPA bout minutes in 0.5 mile network buffers, for older vs. younger adults and median 49% vs 29% MVPA bout minutes in 0.5 mile network buffers, for those recruited from New Mexico vs. from North Carolina). More differences were noted after expanding to a five mile circular residential buffer, with older adults, those recruited from New Mexico, males, those with normal weight, and Non-Hispanic whites completing more of their MVPA bout minutes within the 5 mile circular residential buffer (Table 23). For example, Non-Hispanic Blacks spent less of their MVPA bout minutes within the 5 mile circular residential buffers than other race/ethnic groups (median 61% PA bout minutes vs 80% for Non-Hispanic Whites, p=0.04). Males and females had similar patterns for small buffers; however males completed more of their MVPA bout time within 5 miles of home than females (i.e. median 74% vs. 62% for 5 mile network buffers, p=0.04).

Proportion of Residential Buffers Used for Physical Activity

The median percent of 0.5 and 1 mile residential buffers covered by PA spaces derived from mapping all of a participant's MVPA bout points occurring during the three weeks into a single minimum convex polygon ranged from 33 to 44% (Table 19, C/A in Figure 11). In contrast, the median percent of residential buffers covered by PA spaces derived from mapping independent MVPA bouts into multiple minimum convex polygons was 3% or less. When considering sociodemographic characteristics, differences in use of residential buffer areas for MVPA by race/ethnicity, education, BMI , and recruitment state were noted (e.g. p=0.03, 0.004, <0.0001, and <0.0001, respectively, for the proportion of 0.5 mile network buffers overlapped by the overall PA space; Tables 20, 24, 25). The proportion of residential buffers used for MVPA was smallest for Non-Hispanic Blacks and Hispanics, increased with increasing education, decreased with increasing BMI, and was highest for those recruited from California and North Carolina, regardless of the buffer size (0.5, 1, or 5 mile) or method (circular, network). For example, the overall minimum convex polygon covered the 0.5 mile network buffer a median 58% for Non-Hispanic Whites and 51% for other race/ethnicity vs. 30% for Non-Hispanic Blacks and 40% for Hispanics; 57% for those with a college degree versus 31% for those with a high school education or less and 45% for those with some college; 74% for those of normal body mass index vs. 48% for overweight and 25% for obese individuals; and 87% for those recruited from California and 82% of those recruited from North Carolina vs 31% for those recruited from New Mexico, 24% for those recruited from Ohio, and 38% for those recruited from Pennsylvania.

Percent of Physical Activity Spaces Overlapped by Residential Buffers

Commonly used 0.5 and 1 mile circular and network residential buffers covered a median 2%-55% of PA spaces, with more of the individual bout PA spaces covered (medians ranged from 21% to 55%) than the overall PA spaces (medians ranged from 2% to 12%) (Table 21, C/B in Figure 11). However, a large proportion of overall and bout-based PA space was located within 5 mile circular and network residential buffers (medians ranged from 78% to 99%). Results again varied by sociodemographic characteristics, including age, education, and recruitment state (e.g. p=0.0006, 0.0001, <0.0001, respectively, for overlap between 1 mile network buffers and overall PA space; Tables 32, 26, 27). In general, residential buffers covered a larger portion of PA spaces for older adults, those with a high school education or less, and those recruited from New Mexico and Pennsylvania (e.g. 1 mile network buffers covered a median 15.8% of the overall PA space for older adults vs 5.6% for younger adults ; 16.4% for those with a high school education or less vs 4.2% for those with a college degree ; and 18% for participants recruited from New Mexico and 15% for Pennsylvania vs 2%-6% for those recruited from other sites. Despite these differences, residential buffers in general covered only a small portion of the PA spaces regardless of how they were defined.

Results Limited to Non-Home Physical Activity

In sensitivity analyses limited to MVPA occurring away from the participant's home, a much smaller percentage of non-home MVPA bout time occurred within the residential buffers (medians ranged from 10% to 55%, Table 17). Differences by sociodemographic characteristics were again noted, but patterns differed in some cases from those seen when using total MVPA bout time (Table 29). For example, differences by BMI were noted (e.g. p=0.04 for 1 mile circular buffers), with normal weight individuals having more of their away from home MVPA bout time within the smaller residential buffers than did overweight or obese participants, a pattern not previously seen when considering all MVPA minutes. Additionally, differences by recruitment state were noted (p=0.008 for 1 mile circular buffers), with participants recruited from North Carolina and Pennsylvania having more of their away from home MVPA bout time in residential buffers than did those recruited from New Mexico, again contrary to what was observed when using total MVPA bout time. In contrast, the spatial overlap between residential buffers and PA spaces was similar when considering away from home MVPA bout time as when total MVPA bout time was used (Tables 19 and 21) and differences by sociodemographic characteristics were also generally similar (Tables 30-33). One exception was the importance of age for the percent of PA spaces covered by residential buffers when considering all MVPA points versus its relative unimportance when considering away from home MVPA minutes.

Discussion

This study shows that residential buffers of varying sizes may not be representative of the spatial areas in which PA occurs, both when considering the proportion of PA time spent within residential buffers and in considering the spatial overlap between residential buffers and the newly proposed PA spaces. Of the two proposed definitions of PA space, the individual bout-based method may conceptually most closely approximate the spatial area in which individuals are physically active given that it removes large unused land areas included in the overall PA space definition. In general, this study showed that these individual bout-based PA spaces cover very little of the spatial area within participants' residential buffers regardless of how the residential buffer is defined. At the same time, a large portion of these individual bout based PA spaces are not spatially overlapped by traditionally used 0.5 and 1 mile residential buffers. These patterns held regardless of whether all of a participant's MVPA bout time was used or only the MVPA bout time not located at the participant's home address. These results therefore support the body of literature cautioning against use of residential buffers to assign built environment exposures (10, 19, 20, 31, 46-59, 65), at least as a representation of where individuals are physically active. Efforts to assign built environment exposure for PA using GPS or other tracking methods such as ecological momentary sampling are warranted, particularly for groups who complete little of their PA within residential buffers.

Previous studies have indirectly examined this concept of spatial misalignment of exposure and outcome by demonstrating that the choice of neighborhood definition impacts associations between environmental attributes and health and behavior outcomes (19, 57, 66, 67). For example, choice of buffer type (circular vs. road network) substantially influenced results and even overall conclusions for measures associated with walking (19). In a recent simulation analysis, researchers used both residential neighborhood and individually defined general activity spaces (not PA spaces) to construct environmental exposures (57). They found that neighborhood definitions can systematically and unpredictably bias associations (57). Jago et al. showed that size of neighborhood buffer (400 m vs 1 mi) influenced associations between environmental features and PA among adolescent boys (66). Other research has shown that associations between residential neighborhood contextual factors and *total* PA are diluted as compared with associations between residential neighborhood contextual factors and *residential neighborhood* PA (31, 54, 58, 68). In support of this difference, work by several authors showed that contextual environmental exposures created from residential neighborhood areas were poorly correlated with the same features derived from GPS defined activity spaces (49, 52) and non-home environments (55).

Other studies have examined this question by focusing on the amount of time individuals actually spend in their home neighborhoods. This research has demonstrated that individuals spend considerable time outside of their residential neighborhoods (20, 31, 62, 69, 70). For example, ethnographic work completed on 43 Boston families demonstrated that only 6% of destinations were located within the home census tract whereas 20% were located in adjacent tracts and 74% in non-adjacent tracts (62). Data from adults in New York City showed that only 35% of trip based GPS points were within a 1 km buffer of the home and that the area of the hull connecting these points was on average 54% less than the area of the buffer (70). Specific to PA, Troped et al. 2010 found that less than one-third of PA occurred within the residential neighborhood (31). Likewise, Hillsdon et al. report that 60% of outdoor light, moderate, and vigorous PA was outside the 0.5 mile residential buffer for participants from North West England (69). These results agree with those seen here among the SOPARC GPS sub-study participants, who had nearly 60% of total MVPA time outside of 0.5 mile residential buffers. Further, these results agree with work by Hillsdon et al. in that both suggest geographic factors (recruitment site and urbanicity, respectively) affect the proportion of PA time spent outside buffers (69). In contrast, these results suggested age but not education (a marker of socioeconomic status) affects the proportion of MVPA time outside of a 0.5 mile network buffer, but similar work by Hillsdon et al. in England found that age did not influence this proportion whereas area level affluence (another marker of socioeconomic status) did (69).

Few studies have examined the spatial overlap between activity space and residential buffers. Villanueva et al. found that children only used 25% of their neighborhood as defined by a circular buffer (71). Unfortunately this study does not describe the proportion of the children's activity space encompassed by the circular buffer nor do they indicate the proportion of time spent in specific health behaviors within these overlapping spatial areas. Similarly, others have found that the percent of overall activity space (not limited to that used for PA) overlapping residential buffers of older adults is small (72), in agreement with the results presented here. The present study expands this work by considering both the amount of PA time spent within residential buffers as well as the spatial overlap between residential buffers and activity spaces specific to PA. In particular, a new definition of activity space for PA was proposed for these comparisons, one that creates PA space by combining the spatial areas in which individual bouts of PA occur. This study therefore demonstrated that residential buffers are poor approximations of the spatial areas in which PA occurs.

One limitation of this study is that the participant selection method and non-representative nature of the sample hinders generalizability to a larger population. Further, the differences observed by recruitment site suggest that these patterns may vary by location, necessitating sampling from a broader geographic area than was completed within this study. This study included MVPA using a threshold that likely includes PA achieved through moderate lifestyle activities and only focused on MVPA occurring in bouts of ten or more minutes. Therefore, these results may not directly apply to more purposeful PA at higher intensities or physical activities not completed in bouts. Further, accelerometers used in this study would miss PA achieved through swimming (the accelerometer was taken off), weightlifting, and some biking and thus under-representing the MVPA bouts.

Overall, this study adds to the mounting evidence against using residential buffers to assign built environment exposures without first determining if the residential neighborhood is the appropriate exposure area for the health behavior or factor under consideration. In the case of PA, this study suggests that true PA spaces are likely to differ from the residential environment for many people, particularly when the newly proposed definition of PA space is examined. As others have suggested, using other methods such as GPS monitoring or ecological momentary assessment may be more appropriate for assessing the contextual environments in which PA occurs. Future studies examining the locations of other health behaviors in relation to residential buffers may well extend these findings to other disciplines.

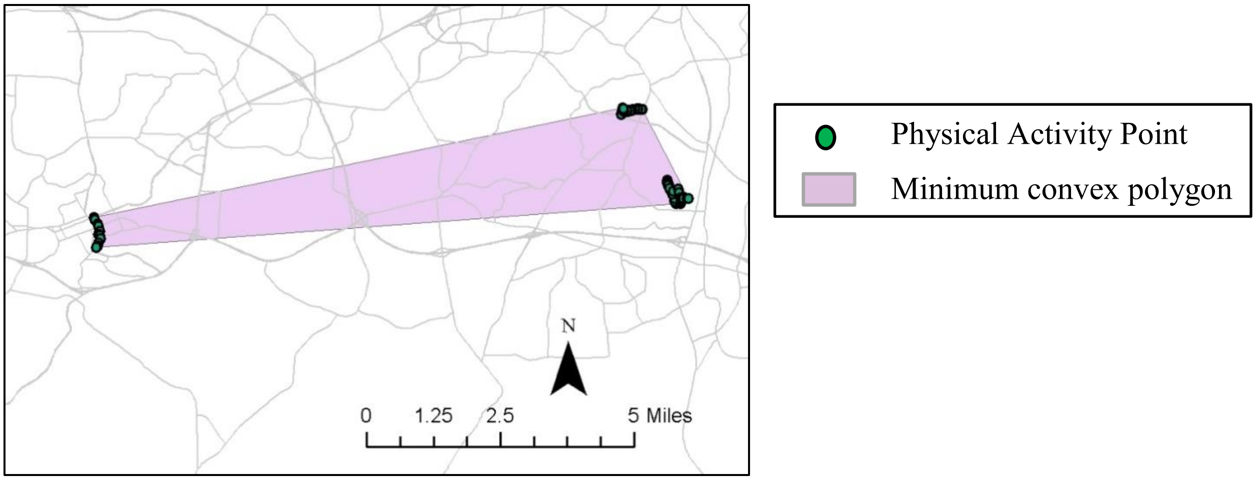


Figure 9. Minimum convex polygon of overall physical activity space compared with actual physical activity GPS points during three physical activity bouts from one individual (simulated data)

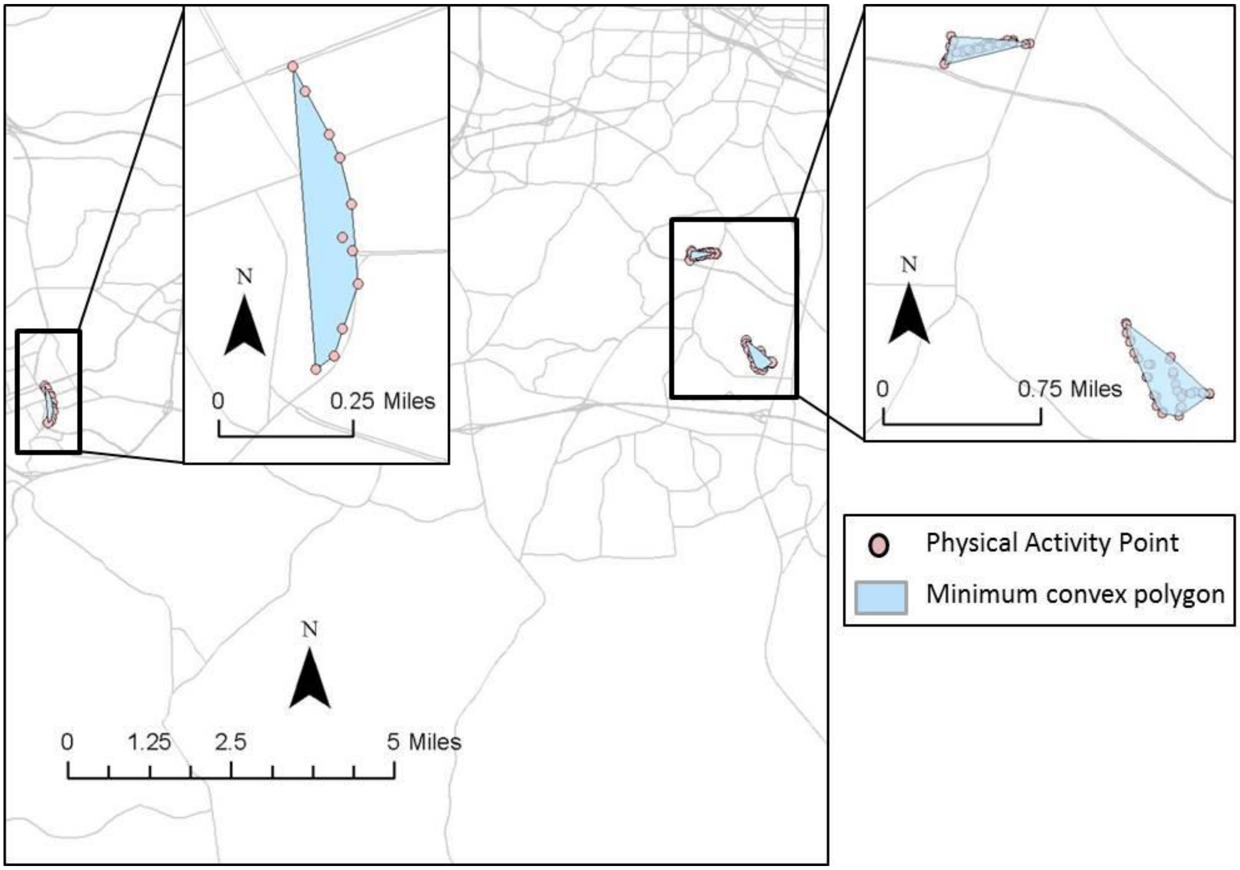


Figure 10. Individual physical activity bout defined minimum convex polygon physical activity space compared with actual physical activity GPS points during the three physical activity bouts from one individual displayed in Figure 1 (simulated data).

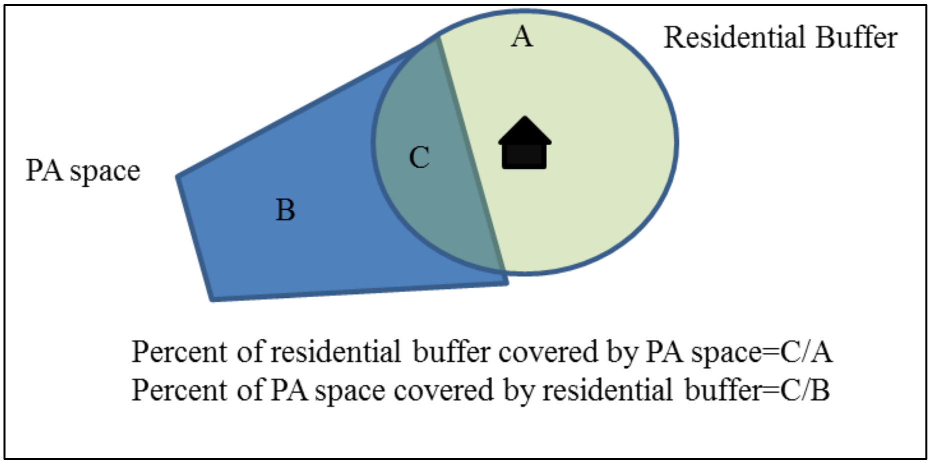


Figure 11. Residential Buffer and PA Space Overlap Definitions

Table 16. Sociodemographic Characteristics of Participants in the SOPARC GPS Study 2009-2011

		Sample [a]		Total Minutes MVPA/Participant [b]
		N	%	Median (IQR)
Overall Number		217	-	
Sex	Male	97	44.7	568 (316, 1014)
	Female	120	55.3	428 (209, 850)
Age 18-35		99	45.6	498 (276, 868)
	36-59	81	37.3	473 (245, 1004)
	60-85	37	17.1	568 (213, 943)
Race/Ethnicity	Non-Hispanic White	109	50.2	580 (294, 1091)
	Non-Hispanic Black	51	23.5	366 (174, 609)
	Hispanic	35	16.1	435 (246, 689)
	Other	21	9.7	638 (349, 877)
	Missing	1	0.5	
Education	High School /GED or less	47	21.7	330 (155, 664)
	Some college or vocational	48	22.1	337 (226, 674)
	College	122	56.2	574 (366, 1020)
BMI	Under or Normal Weight	74	34.1	661 (366, 1033)
	Overweight	71	32.7	557 (366, 900)
	Obese	72	33.2	275 (120, 552)
Recruitment City	Los Angeles, CA	46	21.2	513 (304, 966)
	Albuquerque, NM	45	20.7	469 (197, 671)
	Chapel Hill and Durham, NC	47	21.7	683 (425, 1104)
	Columbus, OH	40	18.4	352 (164, 628)
	Philadelphia, PA	39	18.0	403 (226, 913)
Recruitment Location	Household	46	21.2	437 (274, 687)
	Park	171	78.8	498 (250, 962)
	Missing	0	-	

BMI, body mass index; CA, California; IQR, interquartile range; MVPA, moderate to vigorous physical activity in bouts of at least 10 minutes; NM, New Mexico; NC, North Carolina; OH, Ohio; PA, Pennsylvania

[a] Those who were included in the analysis after exclusions

[b] Moderate to vigorous physical activity ≥760 counts/minute occurring in bouts of 10 minutes or more

Table 17. Median (Interquartile Range) Percent of Moderate to Vigorous Physical Activity Bout Minutes Located within Residential Buffers per Participant in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

	Median (IQR) MVPA Minutes	Median (IQR) Percent MVPA Minutes in Buffer
Total MVPA Minutes	491 (268, 913)	
0.5 mile network	157 (57-328)	39.3 (15.4, 59.9)
0.5 mile circular	173 (71-356)	41.6 (18.6, 63.9)
1 mile network	176 (70-386)	43.6 (19.7, 69.2)
1 mile circular	187 (79-414)	48.1 (22.6, 73.2)
5 mile network	270 (106-529)	65.9 (41.6, 90.7)
5 mile circular	289 (126-569)	74.1 (47.7, 91.7)
MVPA Minutes Not At Home	303 (146, 622)	
0.5 mile circular	21 (0-109)	9.5 (0.0, 35.0)
1 mile circular	33 (0-168)	15.2 (0.7, 44.3)
5 mile circular	142 (27-330)	54.8 (20.1, 84.9)

MVPA, moderate to vigorous physical activity in bouts of at least 10 minutes; IQR, interquartile range

Table 18. Median (Interquartile Range) Percent of Moderate to Vigorous Physical Activity Bout Minutes Located within Residential Buffers by Sociodemographic Characteristics of Participants in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		0.5 Mile Network	*p*[a]	0.5 Mile Circular	*p*[a]	1 Mile Network	*p*[a]	1 Mile Circular	*p*[a]
Age	18-35	32.4 (13.3, 50.7)	0.03	38.4 (17.1, 57.9)	0.05	40.5 (19.6, 58.7)	0.05	43.3 (21.1, 68.4)	0.07
	36-59	41.6 (12.6, 61.2)		42.8 (15.0, 61.9)		45.6 (15.2, 70.4)		49.3 (20.3, 71.7)	
	60-85	45.3 (31.8, 81.4)		47.7 (31.8, 83.5)		59.2 (32.3, 85.4)		62.7 (36.1, 88.5)	
Gender	Female	39.6 (15.7, 58.2)	0.8	42.8 (19.6, 64.9)	0.7	44.4 (21.0, 69.7)	0.8	48.3 (29.7, 73.7)	1.0
	Male	39.3 (15.4, 60.1)		39.3 (16.3, 63.2)		43.3 (19.6, 69.2)		47.9 (20.3, 72.9)	
Race/ Ethnicity	Non-Hispanic White	42.0 (16.2, 64.5)	0.7	44.8 (19.5, 72.0)	0.5	47.4 (20.3, 72.7)	0.4	49.3 (30.5, 76.9)	0.1
	Non-Hispanic Black	35.9 (11.7, 56.8)		38.0 (12.9, 58.2)		38.4 (12.9, 62.5)		38.4 (12.9, 62.7)	
	Hispanic	38.3 (12.6, 61.0)		39.4 (15.4, 66.4)		45.9 (21.9, 78.4)		49.9 (21.9, 87.3)	
	Other	44.2 (20.1, 56.6)		45.7 (20.1, 56.6)		46.0 (20.1, 59.2)		46.0 (20.1, 61.2)	
Education	≤High School	43.0 (21.9, 73.3)	0.3	45.7 (29.0, 78.8)	0.3	52.4 (34.4, 82.7)	0.1	52.4 (34.4, 82.7)	0.2
	Some College	33.5 (13.8, 65.2)		39.2 (17.9, 67.4)		39.9 (18.0, 72.9)		48.3 (26.1, 77.5)	
	College Degree	39.9 (14.8, 56.0)		42.8 (17.1, 60.4)		43.4 (16.8, 62.5)		46.3 (20.3, 69.4)	
Body Mass Index	Normal	34.5 (16.0, 52.9)	0.5	38.8 (19.5, 63.9)	0.9	42.0 (19.7, 68.9)	0.9	46.4 (21.7, 73.2)	1.0
	Overweight	42.8 (19.7, 58.2)		43.0 (20.0, 61.5)		45.9 (20.7, 69.8)		48.4 (24.4, 72.9)	
	Obese	41.6 (12.4, 66.1)		43.3 (13.9, 66.4)		48.0 (14.1, 71.3)		50.2 (18.9, 75.0)	
Recruitment State	California	37.3 (15.4, 58.2)	0.02	41.4 (17.3, 66.4)	0.04	46.9 (20.6, 72.7)	0.04	48.9 (24.4, 77.4)	0.08
	New Mexico	49.3 (29.0, 81.5)		52.9 (31.6, 85.4)		57.2 (32.3, 87.6)		63.8 (36.1, 88.5)	
	North Carolina	29.2 (12.9, 54.8)		33.3 (14.8, 61.2)		37.4 (14.3, 61.1)		45.4 (15.4, 69.6)	
	Ohio	42.2 (8.5, 63.6)		44.4 (15.0, 71.8)		45.2 (15.0, 72.1)		45.5 (15.3, 75.7)	
	Pennsylvania	35.9 (11.3, 47.7)		39.4 (18.6, 52.4)		41.0 (19.4, 53.7)		41.6 (22.7, 54.8)	

[a] Kruskal Wallis *p-value*

Table 19. Median (Interquartile Range) Percent of Residential Buffers Covered by Physical Activity Spaces per Participant in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

	Minimum Convex Polygon [a]	Minimum Convex Polygon Bout [b]
Total MVPA Minutes		
0.5 mile network buffer	44.1 (17.2, 95.1)	3.2 (0.1, 21.0)
0.5 mile circular buffer	40.0 (13.0, 79.5)	1.9 (0.0, 12.6)
1 mile network buffer	36.2 (8.2, 70.8)	1.1 (0.0, 8.2)
1 mile circular buffer	33.4 (7.3, 56.1)	0.6 (0.0, 4.8)
5 mile network buffer	11.2 (1.1, 28.9)	0.1 (0.0, 0.5)
5 mile circular buffer	8.0 (0.8, 20.4)	0.1 (0.0, 0.3)
MVPA Minutes Not At Home		
0.5 mile circular buffer	34.3 (0.2, 79.5)	1.2 (0.0, 11.3)
1 mile circular buffer	25.4 (0.5, 56.1)	0.4 (0.0, 4.4)
5 mile circular buffer	6.7 (0.3, 18.7)	0.1 (0.0, 0.3)

MVPA, moderate to vigorous physical activity in bouts of at least 10 minutes

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 20. Median (Interquartile Range) Percent Residential Network Buffers Covered by Physical Activity Spaces Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		0.5 Mile Network Buffer				1 Mile Network Buffer			
		Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]	Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]
Age	18-35	41.5 (18.4, 94.2)	0.9	3.6 (0.1, 18.7)	0.5	33.2 (10.0, 71.2)	1.0	2.1 (0.0, 8.2)	0.6
	36-59	49.6 (19.6, 91.1)		1.9 (0.1, 20.8)		39.1 (11.6, 64.3)		0.5 (0.0, 7.4)	
	60-85	70.4 (2.2, 99.8)		6.9 (0.0, 24.2)		47.7 (1.0, 81.4)		1.5 (0.0, 11.4)	
Gender	Female	43.7 (6.0, 94.3)	0.4	1.3 (0.1, 19.4)	0.1	36.8 (3.9, 67.1)	0.7	0.6 (0.0, 7.4)	0.1
	Male	44.1 (22.1, 97.3)		4.6 (0.1, 21.5)		34.7 (12.5, 77.1)		1.9 (0.1, 9.8)	
Race/ Ethnicity	Non-Hispanic White	57.9 (22.1, 99.6)	0.03	9.8 (0.1, 22.4)	0.01	47.7 (12.5, 82.8)	0.01	3.4 (0.1, 10.9)	0.008
	Non-Hispanic Black	30.0 (0.9, 70.1)		0.7 (0.0, 7..8)		21.9 (0.5, 47.7)		0.2 (0.0, 3.4)	
	Hispanic	39.5 (19.6, 68.1)		1.0 (0.1, 15.9)		33.2 (15.2, 51.3)		0.5 (0.0, 6.8)	
	Other	50.7 (3.4, 100.0)		10.0 (0.1, 40.2)		47.3 (5.5, 88.6)		2.1 (0.0, 20.6)	
Education	≤High School	30.5 (3.2, 64.8)	0.004	2.0 (0.2, 9.2)	0.006	21.9 (0.8, 39.2)	0.0005	0.5 (0.0, 3.2)	0.007
	Some College	44.9 (8.6 (99.8)		0.5 (0.0, 14.7)		31.3 (5.6, 75.0)		0.2 (0.0, 5.6)	
	College Degree	56.6 (22.3, 100.0)		11.0 (0.1, 26.1)		47.4 (13.8, 85.6)		3.4 (18.3, 95.5)	
BMI	Normal	73.5 (30.5, 100.0)	<0.0001	9.9 (0.3, 27.4)	0.0002	50.8 (27.3, 88.7)	<0.0001	3.8 (0.1, 9.2)	0.0008
	Overweight	48.0 (21.2, 100.0)		6.9 (0.1, 21.5)		38.8 (12.8, 85.6)		1.9 (0.0, 10.9)	
	Obese	24.5 (0.3, 65.8)		0.2 (0.0, 8.9)		17.4 (0.3, 40.4)		0.1 (0.0, 4.0)	
Recruitment State	California	87.0 (44.5, 100.0)	<0.0001	16.0 (0.4, 34.4)	0.0002	62.5 (33.2, 97.0)	<0.0001	6.5 (0.5, 18.2)	<0.0001
	New Mexico	30.8 (3.2, 88.8)		1.3 (0.0, 15.1)		23.9 (2.4, 47.7)		0.4 (0.0, 6.0)	
	North Carolina	82.0 (26.7, 100.0)		10.6 (0.1, 32.3)		63.9 (25.3, 92.1)		4.4 (0.1, 15.9)	
	Ohio	23.8 (0.1, 43.4)		0.1 (0.0, 6.9)		13.2 (0.2, 36.4)		0.1 (0.0, 1.6)	
	Pennsylvania	38.1 (6.2, 73.4)		2.2 (0.1, 17.9)		23.7 (4.4, 49.2)		0.5 (0.0, 6.2)	

BMI, body mass index
[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes
[b] Kruskal Wallis *p-value*
[c] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 21. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Residential Buffers per Participant in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

	Minimum Convex Polygon [a]	Minimum Convex Polygon Bout [b]
Total MVPA Minutes		
0.5 mile network buffer	1.8 (0.4, 9.3)	21.0 (1.8, 56.7)
0.5 mile circular buffer	4.3 (1.1, 21.9)	30.7 (2.8, 67.5)
1 mile network buffer	6.9 (1.5, 27.3)	43.6 (2.9, 83.5)
1 mile circular buffer	12.4 (3.3, 39.1)	55.2 (8.0, 91.8)
5 mile network buffer	77.5 (34.5, 100.0)	97.6 (50.2, 100.0)
5 mile circular buffer	91.5 (52.1, 100.0)	99.3 (62.0, 100.0)
MVPA Minutes Not At Home		
0.5 mile circular buffer	1.9 (0.1, 8.2)	15.3 (0.0, 54.2)
1 mile circular buffer	7.5 (1.1, 26.2)	31.4 (0.0, 86.8)
5 mile circular buffer	87.0 (36.6, 100.0)	97.3 (45.1, 100.0)

MVPA, moderate to vigorous physical activity in bouts of at least ten minutes

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 22. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Residential Network Buffers Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		Minimum Convex Polygon [a]				Minimum Convex Polygon Bout [b]			
		0.5 Mile Network Buffer	*p* [c]	1 Mile Network Buffer	*p* [c]	0.5 Mile Network Buffer	*p* [c]	1 Mile Network Buffer	*p* [c]
Age	18-35	1.6 (0.4, 7.2)	0.0006	5.6 (1.1, 16.4)	0.0006	17.0 (2.0, 59.3)	0.09	38.1 (3.0, 80.7)	0.03
	36-59	1.2 (0.3, 7.2)		4.1 (1.2, 25.9)		20.6 (0.9, 43.2)		37.6 (1.9, 76.1)	
	60-85	5.6 (2.0, 35.2)		15.8 (7.6, 79.4)		34.7 (3.6, 89.3)		75.5 (7.7, 92.5)	
Gender	Female	1.8 (0.5, 7.6)	0.9	6.9 (1.6, 24.9)	0.9	15.8 (1.3, 49.6)	0.2	36.0 (2.3, 80.0)	0.2
	Male	1.8 (0.4, 11.5)		6.9 (1.2, 33.9)		24.1 (3.6, 61.3)		55.6 (6.1, 85.7)	
Race/ Ethnicity	Non-Hispanic White	2.0 (0.4, 7.6)	0.5	7.2 (1.5, 21.3)	0.4	22.9 (2.7, 51.2)	0.8	52.4 (5.8, 85.3)	0.5
	Non-Hispanic Black	2.0 (0.2, 19.0)		8.0 (1.3, 49.8)		15.1 (0.5, 55.9)		30.0 (0.9, 78.2)	
	Hispanic	1.6 (0.6, 14.6)		5.9 (2.4, 35.7)		19.2 (1.3, 59.7)		44.3 (3.0, 84.2)	
	Other	0.7 (0.2, 2.9)		3.9 (0.8, 9.1)		22.0 (9.0, 48.6)		34.4 (2.3, 61.8)	
Education	≤High School	5.9 (0.9, 30.0)	<0.0001	16.4 (2.4, 56.0)	0.0001	59.7 (6.0, 90.1)	0.003	78.2 (13.9, 99.9)	0.007
	Some College	2.4 (0.8, 17.3)		9.3 (2.9, 43.4)		13.1 (1.2, 43.0)		42.1 (2.9, 82.9)	
	College Degree	1.1 (0.2, 3.6)		4.2 (1.0, 12.2)		17.7 (1.9, 37.9)		36.0 (2.3, 70.3)	
Body Mass Index	Normal	1.4 (0.3, 6.1)	0.1	5.0 (1.5, 19.5)	0.09	22.0 (1.8, 50.3)	0.6	46.3 (7.7, 82.0)	0.9
	Overweight	1.7 (0.5, 5.9)		5.6 (1.4, 17.6)		23.2 (2.6, 59.9)		47.3 (5.4, 80.7)	
	Obese	3.0 (0.5, 19.3)		10.8 (1.6, 49.1)		14.6 (0.9, 58.7)		37.9 (2.0, 90.2)	
Recruitment State	California	1.6 (0.6, 7.9)	<0.0001	5.9 (2.1, 35.7)	<0.0001	20.4 (4.1, 42.7)	0.03	44.5 (11.8, 72.3)	0.02
	New Mexico	5.6 (0.5, 19.3)		17.6 (2.6, 40.3)		32.7 (2.6, 64.6)		76.1 (2.7, 98.4)	
	North Carolina	0.5 (0.2, 2.0)		2.1 (0.8, 6.9)		12.7 (0.6, 32.7)		22.8 (1.0, 55.6)	
	Ohio	1.3 (0.2, 9.4)		5.1 (1.0, 25.8)		16.5 (0.3, 62.8)		41.3 (0.6, 87.7)	
	Pennsylvania	4.9 (1.5, 26.0)		14.7 (5.4, 56.4)		37.9 (1.9, 77.3)		56.8 (5.4, 91.2)	

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes
[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity
[c] Kruskal Wallis *p-value*

Table 23. Median (Interquartile Range) Percent of Moderate to Vigorous Physical Activity Bout Minutes Located within Five Mile Residential Buffers by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		5 Mile Network	p [a]	5 Mile Circular	p [a]
Age	18-35	62.7 (39.0, 82.2)	0.006	67.9 (46.7, 86.3)	0.001
	36-59	64.1 (39.7, 90.7)		68.8 (43.3, 93.3)	
	60-85	85.1 (62.9, 98.9)		91.0 (75.8, 99.3)	
Gender	Female	62.2 (38.4, 85.3)	0.06	68.7 (42.5, 90.3)	0.04
	Male	74.1 (47.7, 94.1)		79.7 (51.6, 96.2)	
Race/ Ethnicity	Non-Hispanic White	75.8 (48.6, 91.0)	0.09	79.7 (51.3, 94.1)	0.04
	Non-Hispanic Black	58.0 (30.6, 74.2)		60.6 (31.8, 82.5)	
	Hispanic	67.9 (39.7, 91.7)		75.2 (44.8, 94.5)	
	Other	69.6 (56.6, 88.0)		75.8 (61.5, 90.9)	
Education	≤High School	73.2 (39.7, 93.1)	0.9	74.1 (40.5, 93.9)	1.0
	Some College	64.7 (42.0, 91.8)		68.9 (43.2, 95.3)	
	College Degree	65.7 (43.3, 87.8)		75.5 (49.3, 91.0)	
Body Mass Index	Normal	76.0 (52.9, 93.1)	0.07	80.9 (54.3, 96.2)	0.03
	Overweight	65.9 (40.5, 91.0)		75.8 (51.6, 91.1)	
	Obese	60.9 (32.5, 82.7)		63.5 (33.6, 88.9)	
Recruitment State	California	72.7 (51.8, 95.1)	0.0003	82.8 (57.0, 95.5)	<0.0001
	New Mexico	85.4 (53.7, 97.7)		90.9 (54.3, 99.3)	
	North Carolina	77.8 (49.8, 87.8)		82.2 (56.6, 91.2)	
	Ohio	56.5 (18.3, 81.0)		58.7 (19.7, 82.3)	
	Pennsylvania	52.9 (21.1, 71.2)		52.9 (32.1, 73.3)	

BMI, body mass index
[a] Kruskal Wallis *p-value*

Table 24. Median (Interquartile Range) Percent of Residential Circular Buffers Covered by Physical Activity Spaces Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		0.5 Mile Circular Buffer				1 Mile Circular Buffer			
		Minimum Convex Polygon [a]	*p* b	Minimum Convex Polygon Bout [c]	*p* [b]	Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]
Age	18-35	37.4 (14.5, 78.3)	1.0	2.3 (0.1, 12.2)	0.5	28.5 (8.3, 64.5)	1.0	0.8 (0.0, 4.6)	0.5
	36-59	43.4 (16.8, 77.9)		1.1 (0.0, 12.8)		35.0 (8.3, 54.0)		0.3 (0.0, 4.8)	
	60-85	49.3 (1.5, 89.7)		3.6 (0.0, 14.0)		37.2 (0.7, 67.4)		0.9 (0.0, 6.7)	
Gender	Female	40.4 (6.2, 77.8)	0.5	1.1 (0.0, 11.5)	0.2	33.5 (3.1, 55.0)	0.5	0.4 (0.0, 4.2)	0.08
	Male	40.0 (18.0, 85.5)		2.8 (0.1, 17.3)		33.4 (11.3, 59.9)		0.8 (0.1, 5.7)	
Race/ Ethnicity	Non-Hispanic White	50.3 (16.4, 90.0)	0.01	5.2 (0.1, 17.9)	0.01	38.6 (12.1, 70.7)	0.007	1.9 (0.1, 6.0)	0.004
	Non-Hispanic Black	21.9 (0.5, 51.5)		0.3 (0.0, 4.8)		16.5 (0.3, 40.9)		0.1 (0.0, 1.8)	
	Hispanic	36.9 (18.3, 57.7)		1.1 (0.0, 8.4)		29.8 (12.9, 48.5)		0.3 (0.0, 3.3)	
	Other	51.8 (6.5, 99.2)		3.2 (0.0, 28.6)		35.9 (5.8, 75.3)		1.0 (0.0, 9.3)	
Education	≤High School	25.9 (2.0, 40.9)	0.001	1.1 (0.1, 5.9)	0.007	16.3 (0.5, 34.2)	0.0002	0.3 (0.0, 1.9)	0.009
	Some College	38.2 (7.0, 90.2)		0.4 (0.0, 7.5)		26.2 (3.0, 57.1)		0.2 (0.0, 3.0)	
	College Degree	50.9 (18.3, 95.5)		5.1 (0.0, 18.5)		39.9 (14.0, 71.7)		1.7 (0.0, 7.1)	
BMI	Normal	57.0 (33.2, 95.5)	<0.0001	5.2 (0.7, 14.9)	0.0001	40.0 (20.2, 72.5)	<0.0001	1.8 (0.3, 5.7)	0.0001
	Overweight	44.9 (14.5, 95.7)		3.2 (0.0, 16.5)		34.4 (12.7, 66.6)		0.9 (0.0, 5.7)	
	Obese	18.4 (0.3, 44.3)		0.1 (0.0, 5.7)		14.9 (0.1, 34.7)		0.0 (0.0, 2.2)	
Recruitment State	California	69.9 (36.9, 100.0)	<0.0001	10.0 (1.0, 22.7)	0.0003	49.5 (19.5, 85.6)	<0.0001	3.2 (0.3, 9.7)	<0.0001
	New Mexico	34.5 (3.8, 66.4)		0.7 (0.0, 6.8)		29.4 (1.1, 42.6)		0.2 (0.0, 3.0)	
	North Carolina	58.9 (28.3, 96.8)		5.1 (0.1, 17.9)		46.9. (25.5, 75.3)		1.6 (0.1, 7.1)	
	Ohio	17.0 (0.2, 39.0)		0.1 (0.0, 3.0)		8.8 (0.1, 32.0)		0.0 (0.0, 0.7)	
	Pennsylvania	34.3 (6.5, 69.1)		1.1 (0.1, 12.2)		21.2 (3.3, 40.9)		0.4 (0.0, 4.1)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Kruskal Wallis *p-value*

[c] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 25. Median (Interquartile Range) Percent of Five Mile Residential Buffers Covered by Physical Activity Spaces Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		5 Mile Network Buffer				5 Mile Circular Buffer			
		Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]	Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]
Age	18-35	13.6 (1.8, 29.2)	0.3	0.1 (0.0, 0.4)	0.4	9.3 (1.0, 25.2)	0.07	0.1 (0.0, 0.3)	0.4
	36-59	10.6 (1.6, 33.2)		0.1 (0.0, 0.4)		6.9 (1.0, 22.8)		0.0 (0.0, 0.2)	
	60-85	6.1 (0.2, 24.7)		0.2 (0.0, 0.7)		4.0 (0.1, 11.4)		0.2 (0.0, 0.5)	
Gender	Female	11.3 (0.3, 28.6)	0.4	0.1 (0.0, 0.4)	0.2	7.5 (0.2, 17.6)	0.2	0.1 (0.0, 0.2)	0.1
	Male	11.2 (2.5, 29.0)		0.1 (0.0, 0.5)		9.2 (1.3, 23.4)		0.1 (0.0, 0.3)	
Race/ Ethnicity	Non-Hispanic White	16.7 (2.9, 33.2)	0.02	0.2 (0.0, 0.7)	0.003	10.3 (1.7, 22.8)	0.04	0.1 (0.0, 0.5)	0.006
	Non-Hispanic Black	2.9 (0.1, 16.9)		0.0 (0.0, 0.2)		2.1 (0.1, 11.6)		0.0 (0.0, 0.1)	
	Hispanic	11.6 (2.8, 34.0)		0.1 (0.0, 0.3)		7.7 (1.9, 28.7)		0.0 (0.0, 0.2)	
	Other	16.3 (0.7, 28.9)		0.1 (0.0, 0.8)		11.4 (0.4, 18.7)		0.1 (0.0, 0.5)	
Education	≤High School	2.8 (0.1, 14.2)	<0.0001	0.1 (0.0, 0.2)	0.001	2.1 (0.1, 8.8)	<0.0001	0.0 (0.0, 0.1)	0.002
	Some College	4.7 (0.3, 23.4)		0.0 (0.0, 0.3)		3.8 (0.2, 16.0)		0.0 (0.0, 0.1)	
	College Degree	18.7 (5.2, 35.3)		0.2 (0.0, 0.8)		11.8 (3.0, 26.9)		0.1 (0.0, 0.6)	
BMI	Normal	18.8 (5.9, 36.6)	<0.0001	0.2 (0.0, 0.8)	<0.0001	11.4 (3.1, 28.6)	<0.0001	0.1 (0.0, 0.5)	<0.0001
	Overweight	15.5 (2.7, 35.3)		0.1 (0.0, 0.5)		10.9 (1.8, 31.0)		0.1 (0.0, 0.3)	
	Obese	2.4 (0.1, 16.6)		0.0 (0.0, 0.2)		1.5 (0.1, 12.1)		0.0 (0.0, 0.1)	
Recruitment State	California	20.9 (3.5, 45.8)	<0.0001	0.4 (0.1, 1.2)	<0.0001	12.1 (2.2, 29.1)	<0.0001	0.2 (0.1, 0.7)	<0.0001
	New Mexico	6.2 (0.2, 19.3)		0.0 (0.0, 0.2)		4.0 (0.1, 14.6)		0.0 (0.0, 0.1)	
	North Carolina	24.3 (13.4 (35.3)		0.3 (0.0, 1.2)		16.1 (10.0, 31.9)		0.2 (0.0, 0.7)	
	Ohio	1.6 (0.1, 21.9)		0.0 (0.0, 0.1)		1.0 (0.1, 15.1)		0.0 (0.0, 0.1)	
	Pennsylvania	4.0 (0.6, 14.8)		0.1 (0.0, 0.3)		2.8 (0.4, 9.2)		0.1 (0.0, 0.2)	

BMI, body mass index
[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes
[b] Kruskal Wallis *p-value*
[c] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 26. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Residential Circular Buffers Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		Minimum Convex Polygon [a]				Minimum Convex Polygon Bout [b]			
		0.5 Mile Circular Buffer	*p* [c]	1 Mile Circular Buffer	*p* [c]	0.5 Mile Circular Buffer	*p* [c]	1 Mile Circular Buffer	*p* [c]
Age	18-35	3.5 (1.0, 12.6)	0.0001	10.7 (3.0, 31.5)	0.0005	26.4 (3.0, 65.0)	0.07	54.2 (8.4, 91.6)	0.02
	36-59	2.8 (0.9, 21.2)		8.0 (2.5, 38.6)		25.7 (1.2, 56.8)		44.9 (3.5, 89.4)	
	60-85	14.9 (6.3, 55.8)		25.9 (16.4, 93.7)		52.8 (5.4, 90.1)		87.7 (20.1, 99.8)	
Gender	Female	4.5 (1.2, 19.5)	1.0	12.3 (3.5, 34.8)	0.9	25.1 (2.2, 73.3)	0.4	47.8 (2.8, 91.6)	0.2
	Male	4.2 (1.0, 22.5)		12.4 (2.9, 43.6)		36.9 (5.4, 67.2)		61.8 (13.9, 91.8)	
Race/ Ethnicity	Non-Hispanic White	4.2 (1.1, 18.9)	0.5	12.9 (3.5, 31.5)	0.6	39.8 (5.6, 67.5)	0.8	59.9 (17.7, 91.8)	0.3
	Non-Hispanic Black	4.1 (0.6, 32.6)		12.4 (2.4, 57.5)		23.2 (0.9, 75.6)		31.4 (1.6, 90.4)	
	Hispanic	4.7 (1.8, 26.4)		11.4 (4.3, 47.2)		28.9 (1.9, 72.3)		48.2 (3.0, 98.8)	
	Other	3.5 (0.7, 11.0)		6.8 (2.5, 29.0)		29.3 (9.0, 60.9)		56.0 (9.0, 68.3)	
Education	≤High School	14.5 (1.5, 67.3)	0.001	27.1 (4.3, 67.5)	0.001	72.3 (13.4, 99.2)	0.005	84.0 (13.9, 100.0)	0.04
	Some College	5.5 (1.9, 40.1)		15.6 (4.9, 56.2)		22.4 (1.5, 64.3)		54.3 (6.7, 96.5)	
	College Degree	3.3 (0.8, 11.3)		8.3 (2.6, 23.8)		26.7 (2.3, 59.9)		48.9 (8.0, 82.5)	
BMI	Normal	3.3 (1.0, 15.3)	0.09	11.0 (3.0, 29.0)	0.1	34.5 (9.0, 67.3)	0.7	55.5 (13.6, 91.4)	0.8
	Overweight	3.7 (0.9, 17.4)		9.7 (3.1, 29.1)		30.7 (3.6, 66.8)		59.9 (11.4, 91.8)	
	Obese	6.5 (1.6, 36.5)		20.2 (3.7, 66.3)		21.6 (1.3, 83.2)		46.1 (2.0, 96.4)	
Recruitment State	California	3.1 (1.1, 17.6)	<0.0001	11.0 (3.4, 47.2)	0.0002	28.1 (6.0, 52.3)	0.1	54.7 (12.2, 92.4)	0.06
	New Mexico	23.8 (5.2, 55.8)		23.8 (5.2, 55.8)		43.1 (3.6, 87.7)		87.7 (6.1, 99.8)	
	North Carolina	1.3 (0.5, 5.2)		4.7 (2.1, 16.6)		20.1 (1.0, 42.8)		31.4 (3.7, 68.2)	
	Ohio	3.0 (0.8, 15.0)		7.8 (2.3, 33.5)		30.6 (0.6, 82.4)		54.3 (1.0, 89.1)	
	Pennsylvania	7.2 (2.5, 35.1)		20.7 (7.4, 65.4)		47.4 (2.8, 90.2)		69.0 (13.9, 96.6)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

[c] Kruskal Wallis *p-value*

Table 27. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Five Mile Residential Buffers Stratified by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		Minimum Convex Polygon [a]				Minimum Convex Polygon Bout [b]			
		5 Mile Network Buffer	*p* [c]	5 Mile Circular Buffer	*p* [c]	5 Mile Network Buffer	*p* [c]	5 Mile Circular Buffer	*p* [c]
Age	18-35	72.4 (36.3, 100.0)	0.001	87.1 (50.9, 100.0)	0.002	97.5 (55.6, 100.0)	0.01	99.0 (62.3, 100.0)	0.0008
	36-59	61.6 (24.7, 100.0)		80.5 (41.9, 100.0)		87.8 (19.9, 100.0)		94.7 (28.7, 100.0)	
	60-85	100.0 (79.8, 100.0)		100.0 (93.4, 100.0)		100.0 (88.6, 100.0)		100.0 (94.6, 100.0)	
Gender	Female	74.2 (38.2, 100.0)	0.6	89.1 (54.0, 100.0)	0.4	92.4 (42.2, 100.0)	0.2	97.4 (60.5, 100.0)	0.2
	Male	82.8 (31.7, 100.0)		93.6 (60.9, 100.0)		99.3 (54.6, 100.0)		99.9 (68.0, 100.0)	
Race/ Ethnicity	Non-Hispanic White	74.4 (31.7, 100.0)	0.5	88.1 (47.7, 100.0)	0.5	98.7 (57.8, 100.0)	0.8	99.4 (72.0, 100.0)	0.7
	Non-Hispanic Black	77.7 (37.5, 100.0)		94.4 (52.5, 100.0)		94.7 (19.9, 100.0)		97.9 (30.5 (100.0)	
	Hispanic	79.7 (55.1, 100.0)		93.4 (68.6, 100.0)		97.2 (44.4, 100.0)		98.8 (69.0, 100.0)	
	Other	38.2 (25.7, 100.0)		60.3 (32.3, 100.0)		77.0 (58.1, 100.0)		99.0 (59.9, 100.0)	
Education	≤High School	100.0 (57.9, 100.0)	0.0006	100.0 (77.3, 100.0)	0.002	100.0 (78.2, 100.0)	0.02	100.0 (90.1, 100.0)	0.005
	Some College	83.5 (48.4, 100.0)		94.9 (58.1, 100.0)		97.4 (37.8, 100.0)		99.1 (44.9, 100.0)	
	College Degree	61.3 (25.7, 100.0)		81.4 (40.0, 100.0)		91.2 (38.5, 100.0)		95.1 (59.9, 100.0)	
BMI	Normal	62.5 (31.4, 100.0)	0.1	77.8 (50.9, 100.0)	0.3	97.8 (62.2, 100.0)	0.9	98.9 (77.0, 100.0)	1.0
	Overweight	75.2 (31.7, 100.0)		84.8 (46.2, 100.0)		98.0 (50.9, 100.0)		99.3 (62.3, 100.0)	
	Obese	86.9 (40.7, 100.0)		98.7 (58.0, 100.0)		96.1 (7.7, 100.0)		99.9 (9.5, 100.0)	
Recruitment State	California	74.2 (40.3, 100.0)	<0.0001	89.8 (55.0, 100.0)	0.0007	92.4 (44.4, 100.0)	0.005	98.0 (64.6, 100.0)	0.002
	New Mexico	94.1 (54.5, 100.0)		100.0 (68.6, 100.0)		99.9 (72.8, 100.0)		100.0 (87.7, 100.0)	
	North Carolina	41.6 (18.3, 74.2)		66.5 (30.4, 91.8)		90.8 (33.6, 99.4)		90.8 (39.1, 99.9)	
	Ohio	65.8 (24.7, 100.0)		90.9 (35.2, 100.0)		81.1 (4.2, 100.0)		91.9 (19.3, 100.0)	
	Pennsylvania	100.0 (65.6, 100.0)		100.0 (77.3, 100.0)		100.0 (89.5, 100.0)		100.0 (90.1, 100.0)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

[c] Kruskal Wallis *p-value*

Table 28. Sociodemographic Characteristics of Participants with Physical Activity Bouts Not at the Participant's Home Address in the SOPARC GPS Sub-Study 2009-2011.

		Sample [a]		Minutes Physical Activity [b]
		N	%	Median (IQR)
Overall Number		213	-	
Sex	Male	95	44.6	404 (214, 728)
	Female	118	55.4	256 (97, 532)
Age	18-35	99	46.5	303 (173, 608)
	36-59	81	38.0	287 (139, 622)
	60-85	33	15.5	345 (71, 694)
Race/Ethnicity	Non-Hispanic White	107	50.2	367 (195, 711)
	Non-Hispanic Black	50	23.5	250 (91, 430)
	Hispanic	34	16.0	257 (97, 520)
	Other	21	9.9	336 (250, 666)
	Missing	1	0.5	
Education	High School /GED or less	46	21.6	182 (75, 468)
	Some college or vocational	47	22.1	237 (122, 583)
	College	120	56.3	387 (218, 681)
BMI	Under or Normal Weight	74	34.7	525 (257, 762)
	Overweight	69	32.4	367 (197, 668)
	Obese	70	32.9	180 (52, 330)
Recruitment City	Los Angeles, CA	45	21.1	388 (254, 681)
	Albuquerque, NM	43	20.2	195 (61, 409)
	Chapel Hill and Durham, NC	47	22.1	498 (284, 666)
	Columbus, OH	39	18.3	214 (75, 444)
	Philadelphia, PA	39	18.3	267 (139, 714)
Recruitment Location	Household	45	21.1	290 (195, 527)
	Park	168	78.9	324 (139, 666)
	Missing	0	-	

BMI, body mass index; CA, California; IQR, interquartile range; NM, New Mexico; NC, North Carolina; OH, Ohio; PA, Pennsylvania

[a] Those who were included in the analysis after exclusions

[b] Minutes of moderate to vigorous physical activity ≥760 counts/minute occurring in bouts of 10 minutes or more

Table 29. Median (Interquartile Range) Percent of Not at Home Moderate to Vigorous Physical Activity Bout Minutes Located within Residential Buffers by Sociodemographic Characteristics in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		0.5 Mile Circular	*p* [a]	1 Mile Circular	*p* [a]	5 Mile Circular	*p* [a]
Age	18-35	9.6 (0.0, 25.4)	0.7	15.2 (0.9, 40.7)	0.6	47.2 (20.0, 76.9)	0.01
	36-59	6.2 (0.0, 32.7)		12.7 (0.0, 45.4)		54.3 (13.6, 88.5)	
	60-85	15.5 (0.0, 43.5)		19.2 (3.8, 52.5)		83.9 (36.7, 99.7)	
Gender	Female	9.0 (0.0, 32.7)	0.4	15.1 (0.0, 40.7)	0.3	47.0 (15.7, 79.2)	0.009
	Male	9.5 (0.0, 35.2)		15.2 (1.9, 46.7)		69.3 (31.7, 93.7)	
Race/ Ethnicity	Non-Hispanic White	12.1 (0.0, 36.7)	0.4	26.2 (3.8, 46.7)	0.1	65.4 (29.1, 92.8)	0.09
	Non-Hispanic Black	5.1 (0.0, 25.3)		5.9 (0.0, 26.7)		43.6 (7.0, 67.4)	
	Hispanic	4.2 (0.0, 18.3)		13.6 (0.0, 44.4)		64.8 (22.0, 88.6)	
	Other	6.6 (0.5, 27.6)		11.1 (0.5, 32.0)		69.1 (31.8, 84.5)	
Education	≤High School	14.6 (2.4, 46.6)	0.04	19.2 (3.3, 60.0)	0.5	47.0 (17.4, 81.5)	0.8
	Some College	1.2 (0.0, 24.6)		11.4 (0.0, 46.6)		54.9 (20.0, 94.7)	
	College Degree	9.0 (0.0, 32.3)		14.5 (0.8, 40.2)		57.1 (23.6, 84.2)	
BMI	Normal	14.0 (2.2, 42.3)	0.02	25.8 (5.1, 50.2)	0.04	69.4 (36.8, 94.7)	0.002
	Overweight	9.6 (0.0, 27.6)		15.5 (1.4, 37.9)		54.5 (29.4, 81.9)	
	Obese	2.6 (0.0, 25.4)		7.0 (0.0, 40.6)		31.5 (0.8, 78.7)	
Recruitment State	California	15.5 (3.2, 44.8)	0.05	33.1 (9.0, 69.8)	0.008	76.2 (46.9, 95.4)	<0.0001
	New Mexico	1.2 (0.0, 36.7)		10.1 (0.0, 39.7)		80.9 (31.3, 100.0)	
	North Carolina	10.2 (0.0, 29.7)		14.6 (1.9, 44.3)		73.6 (36.8, 84.7)	
	Ohio	2.4 (0.0, 24.5)		2.9 (0.0, 27.6)		26.1 (2.9, 58.9)	
	Pennsylvania	11.9 (2.3, 36.1)		15.5 (5.4, 44.4)		36.1 (15.5, 54.5)	

BMI, body mass index

[a] Kruskal Wallis *p-value*

Table 30. Median (Interquartile Range) Percent of Residential Circular Buffers Covered by Physical Activity Spaces Stratified by Sociodemographic Characteristics for Physical Activity Bouts Not at Home in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		0.5 Mile Circular Buffer				1 Mile Circular Buffer			
		Minimum Convex Polygon [a]	p [b]	Minimum Convex Polygon Bout [c]	p [b]	Minimum Convex Polygon [a]	p [b]	Minimum Convex Polygon Bout [c]	p [b]
Age	18-35	33.2 (2.0, 78.3)	1.0	1.7 (0.0, 11.3)	0.8	21.5 (2.8, 64.5)	0.9	0.6 (0.0, 4.1)	0.7
	36-59	40.8 (0.0, 77.9)		1.1 (0.0, 11.6)		26.7 (0.0, 52.5)		0.3 (0.0, 4.4)	
	60-85	43.2 (0.0, 89.7)		1.7 (0.0, 9.9)		33.3 (0.0, 67.4)		0.4 (0.0, 5.5)	
Gender	Female	33.3 (0.0, 77.8)	0.4	0.6 (0.0, 9.5)	0.2	22.0 (0.0, 54.2)	0.4	0.3 (0.0, 4.2)	0.1
	Male	35.7 (2.5, 85.5)		2.5 (0.0, 16.9)		25.4 (7.1, 59.9)		0.8 (0.0, 5.4)	
Race/ Ethnicity	Non-Hispanic White	48.1 (8.0, 90.0)	0.008	4.6 (0.0, 17.2)	0.005	37.7 (6.7, 70.7)	0.008	1.7 (0.0, 5.8)	0.002
	Non-Hispanic Black	11.3 (0.0, 45.2)		0.2 (0.0, 1.7)		7.6 (0.0, 37.2)		0.1 (0.0, 0.6)	
	Hispanic	25.4 (0.0, 55.7)		0.9 (0.0, 7.4)		19.5 (0.4, 39.4)		0.3 (0.0, 3.3)	
	Other	48.8 (0.0, 99.2)		2.6 (0.0, 28.1)		35.9 (0.0, 75.3)		0.8 (0.0, 9.1)	
Education	≤High School	20.8 (0.4, 39.8)	0.04	0.9 (0.1, 3.6)	0.01	12.5 (0.1, 33.3)	0.01	0.2 (0.0, 1.3)	0.02
	Some College	35.8 (0.0, 90.2)		0.1 (0.0, 6.6)		19.8 (0.1, 57.5)		0.1 (0.0, 2.8)	
	≥College	44.4 (0.5, 95.5)		3.6 (0.0, 17.9)		36.3 (2.8, 71.7)		1.4 (0.0, 6.6)	
BMI	Normal	53.5 (9.7, 95.5)	<0.0001	4.6 (0.2, 14.9)	<0.0001	39.0 (10.2, 72.5)	<0.0001	1.7 (0.3, 5.7)	<0.0001
	Overweight	37.2 (1.0, 95.7)		2.6 (0.0, 15.5)		30.7 (7.2, 66.6)		0.9 (0.0, 5.4)	
	Obese	7.2 (0.0, 41.3)		0.0 (0.0, 2.2)		3.1 (0.0, 33.2)		0.0 (0.0, 1.0)	
Recruitment State	California	69.9 (33.2, 100.0)	<0.0001	9.5 (1.0, 22.4)	0.0003	48.7 (16.0, 85.6)	<0.0001	3.1 (0.3, 9.1)	<0.0001
	New Mexico	12.7 (0.0, 66.4)		0.5 (0.0, 6.6)		7.7 (0.0, 42.6)		0.1 (0.0, 2.5)	
	North Carolina	58.9 (13.2, 96.8)		4.6 (0.0, 17.9)		44.0 (16.3, 75.3)		1.6 (0.1, 7.1)	
	Ohio	9.9 (0.0, 36.1)		0.1 (0.0, 2.0)		5.5 (0.0, 24.1)		0.0 (0.0, 0.6)	
	Pennsylvania	21.0 (2.0, 69.1)		1.0 (0.0, 8.1)		18.2 (0.5, 40.9)		0.3 (0.0, 2.3)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Kruskal Wallis *p-value*

[c] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 31. Median (Interquartile Range) Percent of Five Mile Circular Residential Buffers Covered by Physical Activity Spaces Stratified by Sociodemographic Characteristics for Physical Activity Bouts Not at Home in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		5 Mile Circular Buffer			
		Minimum Convex Polygon [a]	*p* [b]	Minimum Convex Polygon Bout [c]	*p* [b]
Age	18-35	7.8 (0.4, 25.2)	0.1	0.1 (0.0, 0.3)	0.5
	36-59	6.7 (0.9, 20.1)		0.0 (0.0, 0.2)	
	60-85	2.3 (0.0, 11.4)		0.1 (0.0, 0.5)	
Gender	Female	6.6, 0.0, 15.9)	0.1	0.0 (0.0, 0.2)	0.1
	Male	7.7 (1.0, 20.1)		0.1 (0.0, 0.3)	
Race/Ethnicity	Non-Hispanic White	9.6 (0.9, 22.5)	0.05	0.1(0.0, 0.5)	0.004
	Non-Hispanic Black	1.7 (0.0, 10.3)		0.0 (0.0, 0.1)	
	Hispanic	6.3 (0.7, 21.1)		0.0 (0.0, 0.2)	
	Other	9.3 (0.4, 18.7)		0.1 (0.0, 0.5)	
Education	≤High School	1.8 (0.0, 7.6)	0.001	0.0 (0.0, 0.1)	0.003
	Some College	3.1 (0.1, 13.5)		0.0 (0.0, 0.1)	
	≥College	11.1 (1.2, 24.1)		0.1 (0.0, 0.5)	
BMI	Normal	10.4 (3.0, 26.9)	<0.0001	0.1 (0.0, 0.5)	<0.0001
	Overweight	9.3 (1.6, 28.6)		0.1 (0.0, 0.3)	
	Obese	0.7 (0.0, 7.1)		0.0 (0.0, 0.1)	
Recruitment State	California	12.0 (1.9, 29.1)	<0.0001	0.2 (0.0, 0.7)	<0.0001
	New Mexico	2.2 (0.0, 10.1)		0.0 (0.0, 0.1)	
	North Carolina	15.7 (8.5, 31.1)		0.1 (0.0, 0.6)	
	Ohio	0.8 (0.0, 12.2)		0.0 (0.0, 0.1)	
	Pennsylvania	2.3 (0.1, 9.0)		0.0 (0.0, 0.2)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Kruskal Wallis *p-value*

[c] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

Table 32. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Circular Residential Buffers Stratified by Sociodemographic Characteristics for Physical Activity Not at Home in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		Minimum Convex Polygon [a]				Minimum Convex Polygon Bout [b]			
		0.5 Mile Circular Buffer	*p* [c]	1 Mile Circular Buffer	*p* [c]	0.5 Mile Circular Buffer	*p* [c]	1 Mile Circular Buffer	*p* [c]
Age	18-35	1.2 (0.3, 7.2)	0.4	7.4 (1.5, 24.5)	0.4	16.6 (0.0, 52.1)	0.8	37.5 (2.1, 87.5)	0.5
	36-59	1.7 (0.0, 9.0)		4.8 (0.6, 23.7)		14.6 (0.0, 51.9)		27.1 (0.0, 78.6)	
	60-85	5.2 (0.0, 14.9)		18.8 (0.0, 42.9)		26.9 (0.0, 74.1)		60.6 (0.0, 93.9)	
Gender	Female	1.6 (0.0, 7.4)	0.2	6.8 (0.0, 20.8)	0.3	13.4 (0.0, 48.4)	0.2	22.8 (0.0, 82.0)	0.06
	Male	2.9 (0.3, 14.2)		7.8 (1.8, 32.3)		24.8 (0.0, 62.1)		54.5 (4.6, 89.2)	
Race/ Ethnicity	Non-Hispanic White	1.9 (0.3, 7.8)	1.0	7.5 (1.5, 20.6)	1.0	22.2 (0.0, 52.1)	0.7	48.5 (2.1, 86.8)	0.5
	Non-Hispanic Black	1.5 (0.0, 21.2)		4.3 (0.0, 38.8)		6.5 (0.0, 49.3)		13.3 (0.0, 68.5)	
	Hispanic	2.3 (0.0, 7.7)		9.3 (1.5, 24.5)		6.0 (0.0, 47.4)		18.8 (0.0, 92.1)	
	Other	0.9 (0.3, 7.3)		2.9 (1.1, 29.0)		24.0 (0.0, 60.6)		55.0 (0.0, 63.7)	
Education	≤High School	4.3 (1.0, 26.4)	0.01	15.1 (3.1, 57.3)	0.02	47.4 (1.5, 94.0)	0.002	71.8 (1.5, 99.7)	0.07
	Some College	2.0 (0.0, 11.0)		7.7 (0.5, 34.0)		5.0 (0.0, 43.8)		25.2 (0.0, 87.6)	
	College Degree	1.0 (0.1, 5.8)		4.0 (0.8, 19.6)		15.7 (0.0, 46.7)		29.3 (0.0, 74.6)	
BMI	Normal	2.8 (0.5, 9.0)	0.3	9.7 (2.1, 29.0)	0.3	31.5 (7.6, 67.2)	0.003	54.8 (12.0, 90.8)	0.008
	Overweight	1.9 (0.4, 7.1)		6.1 (1.9, 20.5)		13.3 (0.0, 56.4)		32.9 (0.6, 81.6)	
	Obese	1.2 (0.0, 12.5)		4.6 (0.0, 35.4)		1.7 (0.0, 45.7)		6.3 (0.0, 78.7)	
Recruitment State	California	2.4 (0.6, 8.1)	0.03	9.9 (2.9, 25.9)	0.02	25.1 (3.7, 46.7)	0.4	47.7 (10.5, 84.0)	0.2
	New Mexico	1.3 (0.0, 14.7)		10.8 (0.0, 42.9)		5.7 (0.0, 62.1)		17.4 (0.0, 98.2)	
	North Carolina	0.9 (0.3, 5.2)		3.8 (1.1, 16.6)		14.8 (0.0, 38.9)		24.5 (2.7, 63.7)	
	Ohio	1.0 (0.0, 3.9)		3.2 (0.0, 20.7)		5.1 (0.0, 55.0)		5.1 (0.0, 84.7)	
	Pennsylvania	5.1 (1.0, 24.7)		15.1 (4.3, 60.5)		23.7 (1.2, 77.8)		47.4 (2.1, 90.8)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

[c] Kruskal Wallis *p-value*

Table 33. Median (Interquartile Range) Percent of Physical Activity Spaces Covered by Five Mile Circular Residential Buffers Stratified by Sociodemographic Characteristics for Physical Activity Not at Home in the SOPARC GPS Sub-Study, 2009-2011 (N=217)

		Minimum Convex Polygon [a]		Minimum Convex Polygon Bout [b]	
		5 Mile Circular Buffer	*p* [c]	5 Mile Circular Buffer	*p* [c]
Age	18-35	85.9 (40.7, 100.0)	0.1	98.8 (58.8, 100.0)	0.2
	36-59	70.9 (23.2, 100.0)		86.6 (15.2, 100.0	
	60-85	99.9 (32.7, 100.0)		100.0 (76.2, 100.0)	
Gender	Female	81.3 (27.5, 100.0)	0.1	90.5 (30.1, 100.0)	0.02
	Male	90.2 (41.8, 100.0)		99.6 (54.1, 100.0)	
Race/ Ethnicity	Non-Hispanic White	80.8 (33.2, 100.0)	0.4	96.2 (54.4, 100.0)	0.8
	Non-Hispanic Black	92.7 (29.8, 100.0)		90.8 (16.1, 100.0)	
	Hispanic	92.7 (68.6, 100.0)		98.2 (68.0, 100.0)	
	Other	60.2 (17.0, 100.0)		99.0 (38.6, 100.0)	
Education	≤High School	100.0 (68.6, 100.0)	0.01	100.0 (76.9, 100.0)	0.02
	Some College	88.6 (42.8, 100.0)		94.6 (23.4, 100.0)	
	College Degree	73.9 (29.8, 100.0)		92.2 (37.5, 100.0)	
BMI	Normal	77.8 (46.3, 100.0)	1.0	98.9 (76.2, 100.0)	0.2
	Overweight	82.8 (40.0, 100.0)		98.1 (44.6, 100.0)	
	Obese	92.7 (4.6, 100.0)		81.1 (0.0, 100.0)	
Recruitment State	California	84.2 (47.7, 100.0)	0.04	92.3 (62.0, 100.0)	0.02
	New Mexico	100.0 (52.2, 100.0)		100.0 (34.1, 100.0)	
	North Carolina	60.8 (19.5, 91.8)		90.8 (38.6, 99.9)	
	Ohio	75.8 (11.6, 100.0)		85.1 (0.5, 100.0)	
	Pennsylvania	98.1 (65.0, 100.0)		100.0 (77.8, 100.0)	

BMI, body mass index

[a] Minimum convex polygon for each participant derived from all of their physical activity bout minutes

[b] Multiple minimum convex polygons for each participant derived from each individual bout of physical activity

[c] Kruskal Wallis *p-value*

CHAPTER 7: DERIVING A GPS MONITORING TIME RECOMMENDATION FOR PHYSICAL ACTIVITY STUDIES OF ADULTS

Introduction

Lack of physical activity (PA) is an important contemporary public health concern. It both contributes to the global obesity epidemic and has weight-independent adverse health effects. Although the risks associated with lack of PA are well known, the majority of Americans fail to meet national PA guidelines (4, 5). This pattern is also present in many areas worldwide. Public health researchers have therefore endeavored to identify built environment factors associated with active and inactive lifestyles. One important component of this built environment-PA research may include understanding the types of locations typically used for PA by some populations and potentially under-used by others. Improving understanding of these location use patterns may ultimately facilitate identification of locations for targeted PA interventions. Further, understanding locational context is important for accurately measuring other contextual exposures in the built environment that may influence PA.

While use of global positioning system (GPS) units in PA research has become a more common means of identifying PA locations, it is still a recent technological advancement. As such, few best practice recommendations have been created for researchers (58). Specifically, there is no current recommendation for the number of monitoring days needed to reliably estimate bout-based PA minutes spent in various locations. This is evidenced by a review of GPS-incorporated PA studies that found monitoring time varied drastically, from 40 minutes to 12 days (mean 4 days), and that inclusion of weekdays vs weekend days was inconsistent (18).

In measuring PA, monitoring time recommendations do exist for accelerometers (74). Researchers typically rely on those recommendations when designing protocols for PA studies that combine accelerometer and GPS units due to the lack of an independent standard for GPS (18, 58). However, some have suggested that monitoring time may need to be longer to study locations of PA (58) and have called for the development of an independent recommendation (16, 18, 58).

Therefore, the aim of this project was to provide evidence towards establishing a recommendation for GPS monitoring length in PA studies of adults using data from participants who concurrently wore a GPS and an accelerometer for up to three weeks. This will provide important study planning information for minimizing monetary cost as well as participant burden.

Methods

Study Population

This study used data collected as part of the System for Observing Play and Recreation in Communities (SOPARC) GPS Sub-Study (75). The initial data collection involved recruitment of participants from five communities: Los Angeles, California; Albuquerque, New Mexico; Chapel Hill and Durham, North Carolina; Columbus, Ohio; and Philadelphia, Pennsylvania. Participants (N=248) were recruited from six (seven in the case of Los Angeles) key parks in each of the communities (N=198, 80%) as well as from residences located within one mile of these parks. Participants were ineligible for enrollment if they were <18 years old, non-English speaking, or non-ambulatory. Enrollment occurred in the spring, summer, and fall from May 2009 to April 2011, with most participants enrolled in 2009 and 2010 and only four enrolled in 2011.

Participants completed a survey to provide sociodemographic data, including age, sex, race/ethnicity, and highest level of education achieved. Study staff used a Tanita Bc551 scale and a Seca Portable Stadiometer to measure weight and height, respectively, of participants at enrollment, allowing classification of body mass index (BMI, kg/m^2) into categories of normal weight (<25 kg/m^2), overweight (≥ 25 to <30 kg/m^2), or obese (≥ 30 kg/m^2). Further participant recruitment and study details are available elsewhere (75-77).

Physical Activity and Location Assessment

Participants were asked to concurrently wear an accelerometer and a GPS for three consecutive weeks. Participants wore an ActiGraph (model GT1M; ActiGraph LLC, Pensacola, FL) accelerometer on the right hip, an accelerometer with demonstrated high validity (80). The ActiGraph GT1M was used to measure acceleration in the vertical plane (78) and recorded in 1-minute epochs. Accelerometer non-wear time was identified as 90 minutes of consecutive zero counts, allowing for up to two consecutive minutes of nonzero counts if the 30 minutes before and after those nonzero counts contained no positive counts, and counts for these minutes were set to missing (88). We chose to focus solely on PA only in bouts to conform with the 2008 Physical Activity Guidelines for Americans (3) and the World Health Organization guidelines (85), which specify that PA should be of at least 10 minutes in duration to count towards meeting the weekly goal. PA bouts were defined as ten or more minutes of accelerometer counts occurring above a given cut-point, allowing for 20% of the minutes to fall below the cut-point as long as the first and last minute of a bout were above the cut-point and there were no more than four consecutive minutes below the cut-point. Since the choice of accelerometer count cut-point can substantially influence results (81-83), two common sets of cut-points were used to examine sensitivity of the results to this choice. The chosen sets had comparable validity (84) and included the NHANES cut-points (moderate to vigorous PA (MVPA): ≥2020 counts/min; vigorous PA (VPA): ≥5999 counts/min) (15) and the Matthews' cut-point (MVPA: ≥760 counts/min) (81), notably lower than the NHANES MVPA and VPA cut-points. Although four days of at least 10 hours of wear time were used to define compliant accelerometer wear, sensitivity of results to inclusion of participants with varying numbers of compliant accelerometer wear days (4 or 7) as well as various definitions of a compliant wear day (7-12 hours) was examined.

Geographic location of participants was tracked using a Qstarz BT-Q1000X portable GPS unit (weight, 65 grams; dimensions, 72 x 46 x 20 millimeters) with Wide Area Augmentation System (WAAS) enabled to improve accuracy (75, 77). GPS points with less than a 1-minute epoch were removed. This GPS unit has been shown to have excellent static and dynamic validity in a variety of settings (86). Using a GPS with high performance in terms of validity was key to accurately converting the latitude and longitude points to PA location types. A full description of this process is described elsewhere (94). Briefly, Google Fusion Tables (Google Inc., Mountain View, CA), which incorporates Google Maps (Google Inc., Mountain View, CA) features such as satellite and street view, was used to plot PA bouts. A standardized protocol was used to categorize GPS points into PA location types based on visual interpretation of Google images. Categories were commercial (including large and small stand-alone retail locations, strip malls, dense commercial districts, restaurants, and gas stations), fitness locations including pay gyms and miscellaneous fitness areas (e.g. private tennis/soccer facilities, swim clubs), footpaths, participant homes, parks, residential locations (excluding the participant's home), roads, and schools (from pre-K through university). The protocol calls for consideration of the overall pattern of points within a PA bout when making coding decisions, but allows for points within the same PA bout to be coded differently. For example, if a participant walked along a road to spend time in a park, he or she could have minutes coded as road and park for the same bout. In addition, the historical street view option was used to more accurately match the time period during which the PA bout occurred. The protocol includes directions for using the GPS speed and GPS points to identify and reclassify motorized travel as inactive minutes if necessary. Participant home addresses were geocoded and unmatched addresses imputed with GPS data. Because GPS accuracy is often limited indoors, particularly in large buildings, missing GPS points were imputed if possible following the procedure outlined in the coding protocol. This procedure involved examining the recorded point(s) before and after the missing point(s) to impute the location of the missing point(s), as has been done in other studies of PA involving GPS (16). Study protocols for both the initial data collection and subsequent data analyses were approved by appropriate study site affiliated institutional review boards, and participants provided written informed consent.

Statistical Analyses

The concept of reliability has been used previously to determine the recommended number of monitoring days in PA accelerometry (95-101). Researchers typically use the intraclass correlation coefficient (ICC) and the generalized Spearman-Brown prophecy formula to estimate the number of days needed to reach a specified degree of reliability (102). This method is based on the assumption of parallel tests, which allows calculation of the increase in test length needed (days of monitoring in our case) given the reliability of a part test (single day in our case) to reach a desired level of reliability (103). As such, the number of needed monitoring days can be found by first calculating the ICC for each location category as ICC= $\sigma_b^2 / (\sigma_b^2 + \sigma_w^2)$, where σ_b^2 represents the between (inter) individual variance and σ_w^2 represents the within (intra) individual variance, or day-to-day variance (102). This value represents the reliability of a single day of monitoring (102). Using this information, the Spearman-Brown prophecy formula estimates N, the number of needed monitoring days, as $N=[R_d/(1-R_d)][1-ICC)/ICC]$, where R_d is the desired level of reliability, and ICC is calculated from the model as shown above. This calculation therefore allows estimation of the required number of days even if the recommendation exceeds the 21 days for which participant data was available in this study. The two equations can be generalized, with the reliability for a given number of monitoring days calculated as $R_N= \sigma_b^2/ (\sigma_b^2 + (\sigma_w^2/N))$. While we calculated reliability values for a range of monitoring days, we focused on a desired reliability of at least 80% to provide guidelines for monitoring days, as has been common practice (102).

In this framework, minute-by-minute repeated estimates of PA location types (commercial, fitness, footpath/trail, home, park, residential, road, school) for each participant were reduced to total daily minutes of PA within bouts occurring in each location, the value we were interested in estimating with a degree of reliability. Participants were considered to have zero minutes in a PA location if no PA bout minutes were observed in the location type and the participant was compliant in their accelerometer wear for that day. In turn, participants were considered to have missing minutes in a PA location if they had no PA bout minutes in the location but their accelerometer wear time did not meet the definition of a compliant day for that day (meaning they may have had minutes in the location if they had worn the accelerometer longer).

All analyses were completed within the full sample of included individuals (N=224). Sensitivity analyses were also completed including only those subsets of individuals who engaged in NHANES MVPA bouts (n=192) or VPA bouts (N=47). This was done to provide monitoring day guidelines for the entire study population as well as among the subset of those who actually participated in higher intensity PA bouts.

We constructed negative binomial, random-intercept regression models using SAS PROC GLIMMIX (SAS software version 9.3) with a random intercept for participant and a fixed effect for state of recruitment. The negative binomial model was chosen to account for the skewed nature of the variables representing minutes of PA within bouts occurring in a given location type. These models yielded the between and within person variances used in the generalized Spearman-Brown formula. Confidence intervals for the number of monitoring days were estimated via bootstrapping by resampling, with replacement, 500 times.

Results

Initially, 248 participants were enrolled. Thirteen were excluded due to missing data (two who contributed no accelerometer data and eleven who had all missing data for GPS points), leaving 235 participants for analysis. Of these 235, 224 had at least four ten-hour days of compliant accelerometer wear with 223 completing at least one bout of Matthews' MVPA, 192 at least one bout of NHANES MVPA, and 47 at least one bout of NHANES VPA during the three weeks of monitoring.

Sociodemographic characteristics of participants are displayed in Table 34, including description of those included in the full sample (N=224 who had at least four ten-hour days of compliant accelerometer wear) and the subsets of those who engaged in NHANES MVPA bouts and VPA bouts. Those included in the full sample ranged from 18-85 years of age [mean (SD): 41.1 (15.8)] and 44% were male. Minority groups were represented in the full sample (24% Non-Hispanic Black, 16% Hispanic, 9% Other) as were individuals from varied educational backgrounds (21% ≤high school education, 22% some college or vocational school, 58% college or post graduate degree). BMI was evenly distributed, with 34% under or normal weight, 32% overweight, and 33% obese [mean BMI (SD) 28.3 (6.6)]. Most included Non-Hispanic Blacks were recruited in Ohio and Pennsylvania (64%) and most Hispanics from New Mexico and California (75%). Additionally, a large proportion of included individuals who had post-graduate education were recruited from the North Carolina site (45%) and 67% of those with a high school education or less were recruited from Pennsylvania and Ohio. In general, there were no differences in sociodemographic characteristics between the full sample and those originally enrolled in the study nor the full sample and the subset of those who engaged in higher intensity NHANES MVPA bouts. However, those with NHANES VPA bouts were more educated (p=0.01), had a lower BMI category (p=0.05), and were more likely to be recruited from North Carolina (p=0.02) as compared with the full sample.

In general, most states had physically active participants at all location types; however, fitness facilities and footpaths were only used for VPA bouts in three of the five states (Table 35). Additionally, both participants and minutes of PA were not evenly distributed across the location types (Table 35). For Matthews' MVPA, fitness facilities, schools, and footpaths required the fewest monitoring days (1-4), roads and parks an intermediate number of days (9-11), and participant home, commercial, and residential (excluding the participant's home) location types required the most monitoring days (19-55) to estimate PA bout minutes in a location type with at least 80% reliability.

For the higher intensity NHANES MVPA bout GPS monitoring recommendation, we examined both the full sample of participants (N=224) and the restricted subset of those who participated in NHANES MVPA bouts (N=192). Results were similar for both groups, with slightly more monitoring days needed when restricting to the NHANES MVPA bout subset

(Table 35). Fitness facilities, schools, footpaths, and residential (non-participant home) locations required the fewest number of days (1-2 for both samples). Roads, parks, and homes required an intermediate number of days (5-16 for the full sample and 16-25 for the NHANES MVPA bout subset). Commercial areas required the most (105 for the full sample and 119 for the NHANES MVPA bout subset).

For the NHANES VPA bout GPS monitoring recommendation, we again examined the full sample of participants (N=224) and the restricted subset of those who participated in NHANES VPA bouts (N=47) (Table 35). All location types (fitness facilities, schools, footpaths, roads, homes, and parks) required only one day when considering the full sample of participants. When restricting to the subset with VPA bouts, sample sizes for the number of states, participants, and minutes of PA in each location decreased drastically. Roads and homes required nine and ten monitoring days respectively, commercial locations required 119 days, and all other location types remained low at 2 monitoring days.

Recommended number of GPS monitoring days needed to reach 80% reliability were generally similar in sensitivity analyses based on definitions of compliant accelerometer wear other than the minimum four, ten-hour days used for the main results (combinations of 4 or 7 days and 7-12 hours of wear examined, Tables 36-37). Three exceptions were the residential (non-participant home) location for Matthews' MVPA bouts, for which some analyses suggested fewer needed GPS monitoring days, commercial locations for NHANES MVPA bouts, for which a small number of analyses suggested fewer needed GPS monitoring days, and roads for NHANES VPA bouts for which some analyses suggested more needed monitoring days.

In general, reliability improved more rapidly with increasing numbers of monitoring days for the higher intensity NHANES MVPA and VPA bouts than for Matthews' MVPA bouts, regardless of whether the full or subsetted samples were used for NHANES MVPA bout and VPA bout calculations (Figures 12-14). Reliability for many location types had not yet crossed the desired 80% reliability threshold after four to seven days of monitoring, which is the recommended range for accelerometer monitoring (74).

Discussion

A longer GPS monitoring period is necessary to reliably estimate the PA bout minutes spent in important PA locations where built environment interventions could be implemented. This study suggests that 12 days would capture Matthews' MVPA, NHANES MVPA, and NHANES VPA in roads and parks in a sample containing a mix of active and inactive individuals. Interventions targeting increasing PA at home, one of the most commonly used PA locations in this sample, would need nearly 20 days of GPS monitoring in order to reliably estimate at home MVPA time.

The number of days participants need to wear a GPS to reach 80% reliability for estimating the number of PA bout minutes in various locations depended on the specific location type, intensity, and distribution of minutes across all participants. For example, fitness locations consistently needed limited numbers of monitoring days (1-2) whereas commercial locations often required extremely long monitoring periods (55-119 days). Time in fitness locations was contributed by a small number of participants (n=40 for Matthews' MVPA bouts) as compared with those in commercial locations (n=147 for Matthews' MVPA bouts). Additionally, PA bout minutes at fitness locations were less variable from day-to-day than PA bout minutes at commercial locations. A large proportion of PA bout minutes in commercial locations were completed by just a few individuals, who would be expected to drive the monitoring time estimates downwards due to their large between-person variation when compared to their relatively smaller within-person variation. However, the effect of these few individuals was overshadowed by the large number of participants who had an intermediate amount of PA bout minutes in commercial locations on only a few days of their monitoring. These individuals collectively increased the within-person variation, thereby increasing the monitoring day recommendation overall.

For lower intensity Matthews' MVPA bouts, which was defined by a cut-point that included activities of daily living, only minutes spent in fitness facilities, schools, and footpaths could consistently be assessed using the typical four or seven days of monitoring based on accelerometer monitoring recommendations. In order to reliably estimate bout minutes of Matthews' MVPA spent in other important built environment locations, like roads and parks, monitoring days would need to be increased to twelve days. Although the home is an important location for PA bouts, the number of needed monitoring days was quite long. This is likely due to the large variety of Matthews' MVPA that can occur at home, including intentional and unintentional MVPA, which could result in large day to day variability in MVPA bout minutes. Similarly, minutes of Matthews' MVPA in bouts at commercial and residential (non-participant home) locations is likely best captured through means other than GPS given the extremely long monitoring time requirements suggested by this sample. At the same time, the proportion of MVPA or VPA bout minutes occurring in many of the non-home locations that required long monitoring periods was fairly small for this sample, with the exception of commercial locations in some subgroups (e.g. 23% of Matthews' MVPA bout minutes for Hispanics).

In addition, sensitivity analyses demonstrated that monitoring recommendations may vary with the proportion of individuals in the sample who engaged in PA bouts of a given intensity. For example, VPA bouts were uncommon in this sample, with only 21% of participants completing a VPA bout. The main analysis included the full sample of participants and therefore estimates how many monitoring days are required in a population with a large proportion of participants who consistently have zero bouts of VPA. These individuals with no VPA bouts have small between day variation, which decreases the estimates of needed monitoring days for the full sample. The sensitivity analysis restricted to only those individuals who completed at least one bout of VPA estimates how many monitoring days are required to estimate the number of VPA bout minutes in a population in which everyone participates in VPA bouts. This analysis eliminated many of the individuals with no between day variation (those who consistently do no VPA) and subsequently increased recommendations to ten days for road and home locations, although recommendations for the other location types remained low. Therefore, it is important to consider the proportion of individuals who complete PA bouts of a given intensity in a population and to decide whether focus is on estimating the bout minutes of PA within the population overall or only among the subset of those who engage in bouts of PA of a given intensity when deciding on length of GPS monitoring.

In some cases, the observed number of required monitoring days calculated from the original sample fell outside the 95% confidence interval as estimated through bootstrapping. Due to the nature of bootstrapping, this phenomenon is possible under certain circumstances. For example, PA bout minutes in the commercial location were in part contributed by a few individuals who had extremely high minutes of commercial activity at moderate consistency over the three weeks (likely employees of the commercial locations). These individuals contributed considerably to increasing the ICC for commercial locations (and thus lowering the number of monitoring days) given the large influence they have on between person variance due to the large difference between their individual mean commercial minutes and the overall mean commercial minutes. Bootstrapping allowed for resampling of these individuals, resulting in a higher proportion of individuals in the sample with this PA bout pattern. When this occurs, the monitoring time recommendations for many bootstrapped samples will be lower than the original sample that contained each individual only once.

Much PA research focuses on PA occurring within home neighborhoods. While the methods used in this study could be extended to examine how many days of monitoring are required to reliably estimate PA minutes spent in the home neighborhood, participants in this study spent a large proportion of their PA bout minutes outside of the home neighborhood as measured by various residential buffers (104). Therefore, this study focused on estimating PA bout minutes occurring in specific location types regardless of whether they were within or outside of the home neighborhood.

One limitation of this study is that the sampling strategy, in which many participants were recruited from parks, hinders generalizability. Individuals who spend time in parks may be more likely to be physically active or more likely to be active in parks. However, a large proportion of the sample did not participate in vigorous PA bouts, and park use was not exceptional (79% of those with Matthews' MVPA bouts were recruited from parks but only 57% of them had MVPA bout minutes in a park; 76% of those with NHANES MVPA bouts were recruited from a park but only 43% of them had MVPA bout minutes in a park; 83% of those with VPA bouts were recruited from a park yet only 13% of them had VPA bout minutes in a park). A second limitation is that these monitoring recommendations cannot be directly applied to studies of participants less than 18 years of age. Third, the same cut-points were used for all participants to define intensity of PA bouts for consistency; however these cut-points may not be valid across the age span of 18-85 (90). Fourth, some coding and analytic decisions may impact the results. For example, the protocol allowed for imputation of missing GPS points. Imputation was completed for 34% of missing GPS points for Matthews' MVPA bout minutes (6% of the total Matthew's MVPA bout minutes). Sensitivity analyses showed that had this imputation not been completed, the estimated wear day recommendation would have changed slightly only for those locations with very high recommended wear days (e.g. >20 days). Also, the coding protocol allowed for more detailed categorization of locations than could be used in this analysis due to sample size. For example, commercial areas were further coded as large and small stand-alone retail locations, strip malls, dense commercial districts, restaurants, and gas stations. Grouping of these locations may hide patterns of variability for each specific location. Finally, 5% of Matthews' MVPA bout minutes (and less for NHANES MVPA and VPA bout minutes) were coded into an "other" category and therefore could not be assessed using this method.

Despite these limitations, the data used for this analysis have several strengths. First, the included participants were from diverse geographic locations and sociodemographic backgrounds. Second, they wore a GPS that has been ranked highly for accuracy across a variety of settings (86), and the data coding protocol allowed for precise location classification. Additionally, participants wore the accelerometer and GPS for up to three weeks, providing a longer sampling time than many PA studies. Combined, these strengths suggest this sample is suitable to contribute evidence towards a GPS monitoring time recommendation for PA studies.

Conclusions

In conclusion, the often-used 4 or 7 days of monitoring for GPS (18, 58) may not be accurate for estimating bout minutes of PA in certain location types. Indeed, using GPS to estimate bout minutes of PA in some locations may be impractical due to the lengthy monitoring time recommendations. Fortunately, many of the locations in which individuals undertake intentional PA may be reasonable to monitor with GPS (fitness facilities, roads, parks, schools). These results may vary by sociodemographic characteristics of the sample considered and should therefore be investigated in other populations before finalized recommendations for GPS monitoring time are developed. At present, this study suggests that 12 days of monitoring may reliably estimate both MVPA and VPA bout minutes in fitness facilities, footpaths, parks, roads, and schools for populations in need of interventions. Importantly, this recommendation includes adequate monitoring for several key built environment locations that may be useful for increasing PA at the population level.

Table 34. Participant Sociodemographic Characteristics, SOPARC GPS Sub-Study 2009-2011

		Full Sample [a]		NHANES MVPA Subset [b]		NHANES VPA Subset [c]	
		N	%	N	%	N	%
Overall Number		224	-	192	-	47	-
Sex	Male	98	43.8	88	45.8	20	42.6
	Female	126	56.3	104	54.2	27	57.4
Age	18-35	103	46.0	91	47.4	27	57.5
	36-59	81	36.2	69	35.9	17	36.2
	60-85	40	17.9	32	16.7	3	6.4
Race/Ethnicity	Non-Hispanic White	113	50.7	104	54.2	31	66.0
	Non-Hispanic Black	53	23.8	37	19.3	7	14.9
	Hispanic	36	16.1	31	16.2	4	8.5
	Other	21	9.4	19	9.9	5	10.6
	Missing	1	0.4	1	0.5	0	-
Education	≤High School	48	21.4	35	18.2	3	6.4
	Some college or vocational	50	22.3	39	20.3	7	14.9
	College	126	56.3	118	61.5	37	78.7
BMI	Under or Normal Weight	77	34.4	74	38.5	21	44.7
	Overweight	72	32.1	64	33.3	19	40.4
	Obese	75	33.5	54	28.1	7	14.9
Recruitment City	Los Angeles, CA	47	21.0	45	23.4	10	21.3
	Albuquerque, NM	47	21.0	39	20.3	5	10.6
	Chapel Hill and Durham, NC	49	21.9	48	25.0	21	44.7
	Columbus, OH	41	18.3	28	14.6	5	10.6
	Philadelphia, PA	40	17.9	32	16.7	6	12.8
Recruitment Location	Household	46	20.7	44	22.9	8	17.0
	Park	176	79.3	146	76.0	39	83.0
	Missing	2	0.9	2	1.0	0	-

BMI, body mass index; CA, California; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; NM, New Mexico; NC, North Carolina; OH, Ohio; PA, Pennsylvania; VPA, vigorous physical activity

[a] Those who were included in the full sample; 223 of whom engaged in MVPA bouts (Matthews' definition, ≥760 counts/min)

[b] Subset engaged in NHANES MVPA bouts (NHANES definition, ≥2020 counts/min)

[c] Subset who engaged in NHANES VPA bouts (NHANES definition, ≥5999 counts/min)

Table 35. GPS Monitoring Recommendations for Estimating Minutes of Physical Activity in Bouts for Various Location Types with ≥80% Reliability Given Compliant Accelerometer Wear of at Least Four, Ten-Hour Days from the SOPARC GPS Sub-Study 2009-2011

		States (N)	Participants (N)	Minutes (N)	Full Sample Monitoring Days [d] (95% CI [f])	Active Subset Monitoring Days [e] (95% CI [f])
Matthews' MVPA [a]	Fitness	5	40	6,092	1 (1, 2)	
	School	5	97	11,064	3 (2, 4)	
	Footpath/Trail	5	64	2,016	4 (1, 4)	
	Road	5	165	21,885	9 (5,10)	
	Park	5	126	19,465	11 (4, 10)	
	Home	5	205	42,735	19 (8, 20)	
	Residential	5	83	5,053	48 (2, 5)	
	Commercial	5	147	12,375	55 (8, 31)	
NHANES MVPA [b]	Fitness	5	31	3,565	1 (1, 2)	1 (1, 2)
	School	5	53	4,242	1 (1, 2)	2 (1, 2)
	Footpath/Trail	4	40	1,352	1 (1, 3)	2 (1, 3)
	Road	5	127	12,820	12 (5, 11)	16 (6, 15)
	Park	5	82	5,808	5 (2, 6)	31 (2, 11)
	Home	5	133	9,447	16 (5, 12)	25 (7, 18)
	Residential	5	36	1,009	2 (2, 3)	2 (2, 3)
	Commercial	5	65	1,573	105 (2, 3)	119 (2, 10)
NHANES VPA [c]	Fitness	3	13	1,023	1 (1, 2)	2 (1, 9)
	School	5	11	634	1 (1, 2)	2 (1, 3)
	Footpath/Trail	3	10	478	1 (1, 1)	2 (1, 4)
	Road	5	21	1,250	1 (1, 2)	9 (1, 14)
	Park	5	6	227	1 (1, 2)	2 (1, 5)
	Home	5	19	944	1 (1, 2)	10 (3, 22)
	Residential	1	2	112	1 (1, 2)	1 (1, 3)
	Commercial	4	9	206	1 (1, 4)	119 (1, 432)

CI, confidence interval; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

[a] MVPA bouts defined by Matthews' definition, ≥760 counts/minute

[b] MVPA bouts defined by NHANES definition, ≥2020 counts/minute

[c] VPA bouts, defined by NHANES definition, ≥5999 counts/minute

[d] Those who were included in the full sample; also represents those who engaged in Matthews' MVPA bouts

[e] Subset engaged in NHANES MVPA bouts or VPA bouts

[f] See text for explanation of cases where point estimate lies outside the 95% CI

Table 36. GPS Monitoring Recommendations for Estimating Minutes of Physical Activity in Bouts for Various Location Types with ≥80% Reliability Given Various Definitions of Compliant Accelerometer Wear from the Full Sample of SOPARC GPS Sub-Study Participants

	Days	4						7					
	Hours	7	8	9	10	11	12	7	8	9	10	11	12
Matthews' MVPA[a]	Fitness	1	1	1	1	1	1	1	1	1	1	1	1
	School	3	3	3	3	3	2	3	3	3	3	3	3
	Footpath/Trail	5	4	4	4	4	3	5	4	4	4	4	4
	Road	9	10	9	9	8	7	9	10	9	9	9	7
	Park	11	11	11	11	12	15	11	11	12	12	12	13
	Home	24	22	18	19	19	20	23	22	18	19	19	18
	Residential	49	47	46	48	51	70	49	47	44	2	2	5
	Commercial	50	50	54	55	64	56	51	53	55	55	60	53
NHANES MVPA[b]	Fitness	1	1	1	1	1	1	1	1	1	1	1	1
	School	2	2	1	1	1	1	2	2	1	1	1	1
	Footpath/Trail	2	2	2	1	2	2	2	2	2	2	2	2
	Road	12	12	12	12	12	11	12	13	12	12	13	10
	Park	6	5	4	5	4	5	8	5	5	5	6	45
	Home	13	14	14	16	16	15	13	14	15	16	15	13
	Residential	2	2	2	2	2	2	2	2	2	2	3	2
	Commercial	3	3	95	105	116	107	3	3	3	107	106	104
NHANES VPA[c]	Fitness	1	1	1	1	1	1	1	1	1	1	1	1
	School	1	1	1	1	1	1	1	1	1	1	1	1
	Footpath/Trail	2	2	2	1	1	1	2	2	2	2	1	1
	Road	1	1	1	1	1	1	1	1	1	1	1	1
	Park	1	1	1	1	1	1	1	1	1	1	1	1
	Home	1	1	1	1	1	1	1	1	1	1	1	1
	Residential	2	2	1	1	2	2	2	2	1	1	2	2
	Commercial	2	2	2	1	1	1	2	2	2	1	1	1

CI, confidence interval; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

[a] MVPA bouts defined by Matthews' definition, ≥760 counts/minute

[b] MVPA bouts defined by NHANES definition, ≥2020 counts/minute, analysis includes the full sample of N=234 participants

[c] VPA bouts, defined by NHANES definition, ≥5999 counts/minute, analysis includes the full sample of N=234 participants

Table 37. GPS Monitoring Recommendations for Estimating Minutes of Physical Activity in Bouts for Various Location Types with ≥80% Reliability Given Various Definitions of Compliant Accelerometer Wear from the Active Subset of SOPARC GPS Sub-Study Participants

	Days	4						7					
	Hours	7	8	9	10	11	12	7	8	9	10	11	12
NHANES MVPA [a]	Fitness	1	1	1	1	1	1	1	1	1	1	1	1
	School	2	2	2	2	2	1	2	2	2	2	2	1
	Footpath/Trail	2	2	2	2	2	2	2	2	2	2	2	2
	Road	17	17	16	16	17	15	17	17	16	16	19	13
	Park	27	18	14	31	39	48	27	14	15	29	38	46
	Home	22	22	23	25	24	21	22	22	24	25	23	19
	Residential	3	3	2	2	2	2	3	3	3	2	3	3
	Commercial	5	80	101	119	130	116	5	89	109	120	114	112
NHANES VPA [b]	Fitness	2	2	2	2	2	2	2	2	2	2	2	2
	School	2	2	2	2	2	2	2	2	2	2	2	2
	Footpath/Trail	2	2	2	2	2	2	2	2	2	2	2	2
	Road	35	35	13	9	12	36	35	35	13	9	12	36
	Park	2	2	2	2	2	2	2	2	2	2	2	2
	Home	10	10	9	10	10	14	10	10	9	10	8	11
	Residential	3	3	2	1	3	3	3	3	2	2	3	3
	Commercial	140	134	127	119	132	116	140	134	127	119	133	118

CI, confidence interval; MVPA, moderate to vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; VPA, vigorous physical activity

[a] MVPA bouts defined by NHANES definition, ≥2020 counts/minute, analysis includes only individuals who completed NHANES MVPA bouts, (N=192)

[b] VPA bouts, defined by NHANES definition, ≥5999 counts/minute, analysis includes only individuals who completed NHANES VPA bouts (N=47)

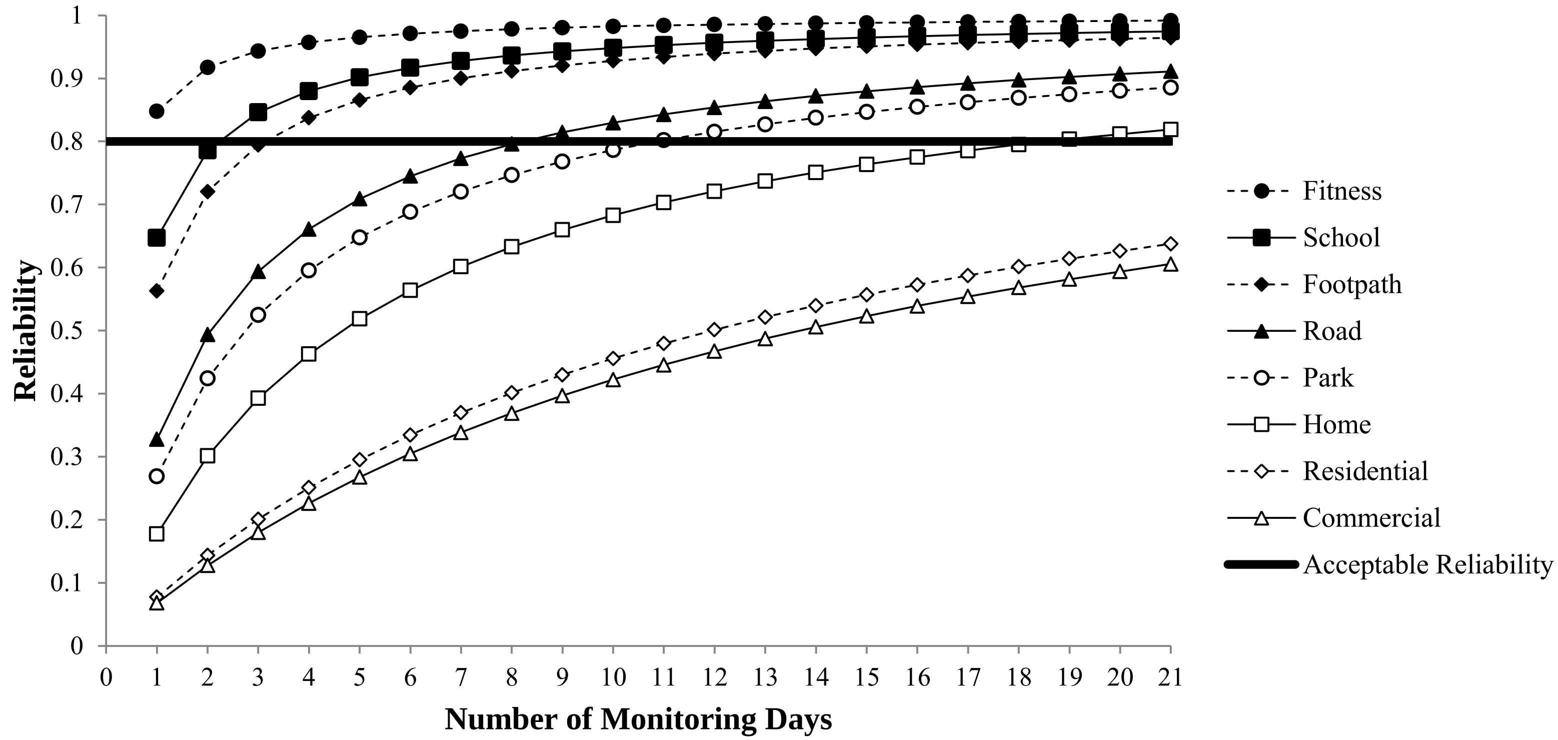


Figure 12. Number of GPS Monitoring Days Needed to Estimate Minutes of Physical Activity in Matthews' Moderate to Vigorous Physical Activity Bouts Occurring in Locations Types for Varying Levels of Reliability Given at Least Four Ten-Hour Days of Accelerometer Wear from the SOPARC GPS Sub-Study 2009-2011

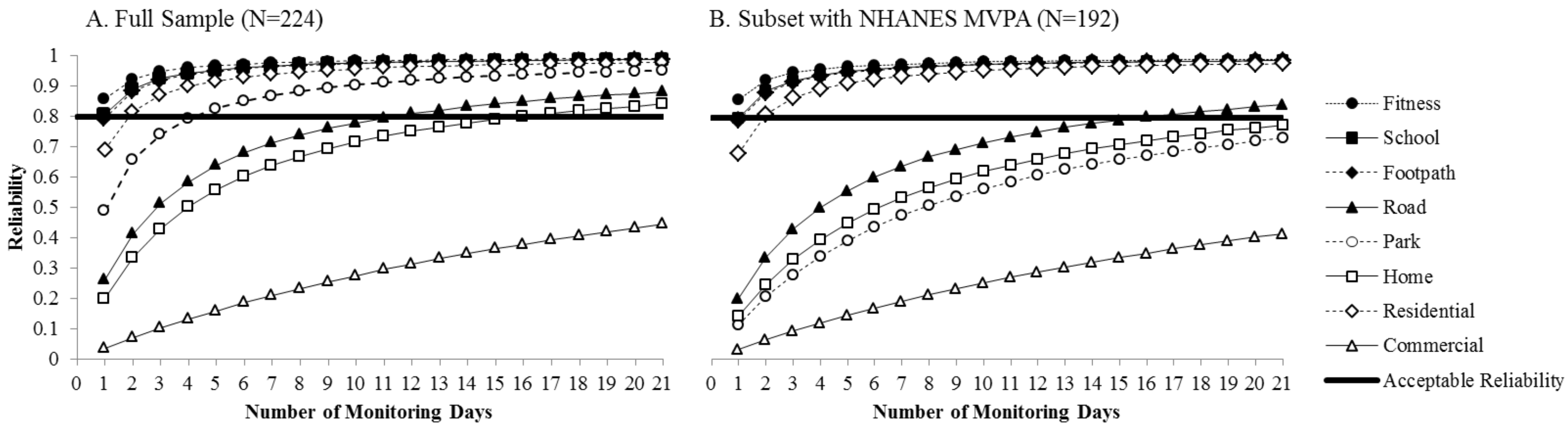


Figure 13. Number of GPS Monitoring Days Needed to Estimate Minutes of Physical Activity in NHANES Moderate to Vigorous Physical Activity Bouts Occurring in Location Types for Varying Levels of Reliability Given at Least Four Ten-Hour Days of Accelerometer Wear among A) the Full Sample of Participants Completing Matthews' Moderate to Vigorous Physical Activity Bouts (MVPA) and B) the Subset of Participants with NHANES MVPA Bouts from the SOPARC GPS Sub-Study 2009-2011

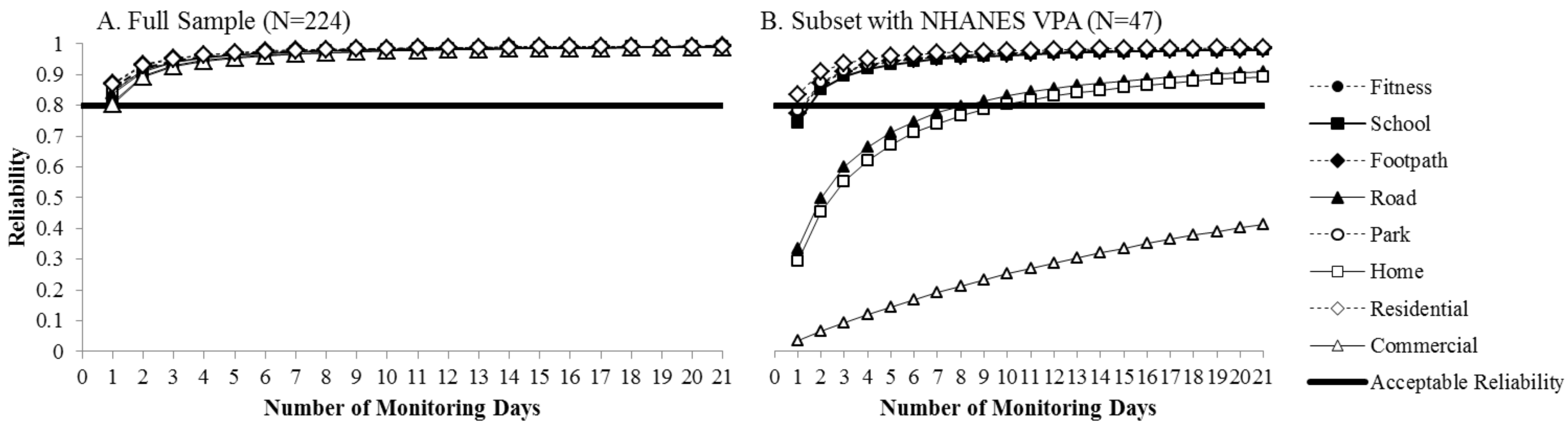


Figure 14. Number of GPS Monitoring Days Needed to Estimate Minutes of Physical Activity in NHANES Vigorous Physical Activity Bouts Occurring in Location Types for Varying Levels of Reliability Given at Least Four Ten-Hour Days of Accelerometer Wear among A) the Full Sample of Participants Completing Matthews' Moderate to Vigorous Physical Activity Bouts (MVPA) and B) the Subset of Participants with NHANES Vigorous Physical Activity Bouts (VPA) from the SOPARC GPS Sub-Study 2009-2011

CHAPTER 8: CONCLUSIONS

Overall Summary

This research contributes significantly to understanding spatial patterns of PA among a sociodemographically and geographically diverse adult population. It both improves substantive knowledge of the locational contexts in which adults are active and provides methodologic guidance for future studies examining the relationship between the built environment and adult PA. Specific Aim 1 provides a new PA location coding protocol and describes the specific locations in which adults from five United States cities engage in PA over a three week period, providing information useful for planning targeted interventions in communities. Specific Aim 2 provides methodologic input for the practice of assigning built environment exposures using residential buffers in studies of the built environment-PA relationship by examining the spatial relationship between residential buffers and newly proposed PA spaces for adults. Finally, Specific Aim 3 provides study procedural information regarding the length of time GPS monitoring devices should be worn in order to reliably estimate minutes spent in PA at various locations.

Where are adults active?

Most adults in the United States fail to engage in the 150 minutes of recommended aerobic PA per week (4, 5). This research suggests that when adults do engage in ten minute or more bouts of PA, which are of sufficient length to contribute towards meeting the weekly recommendation, they tend to spend that time in their own home or on roads. Parks were frequently used for MVPA, notably in patterns indicative of their potential to reduce disparities in access to recreational facilities. Finally, fitness centers and schools were frequently used for VPA. In all cases, specific sociodemographic and geographic patterns were noted that will enable public health professionals and urban planners to more effectively implement Community Preventative Services Task Force recommended interventions designed to increase PA in communities.

<u>Do residential buffers represent adult PA space?</u>

Circular or network buffers around the residential address are often used to estimate exposures relevant to PA yet little is known about how these residential buffers align with the true locations of adult PA. This research suggests that adults spend a great deal of their bout-based PA time outside of these residential buffers, particularly when considering their PA away from home. Further, the spatial overlap between these residential buffers and conceptualized PA space is poor in many cases, with adults simultaneously using a small proportion of their residential buffer for PA bout time and having a large proportion of their PA space outside of their residential buffer. Although differences by sociodemographic and geographic characteristics were noted, no groups had residential buffers that appeared representative of their PA space. These results support previous assertions that use of residential buffers for PA exposure areas ensnares research in the "residential trap" (46). Future studies examining built environment effects on PA should leverage monitoring methods such as GPS or ecological momentary sampling that allow identification of a more spatially accurate summarization of true PA space.

How long should a GPS be worn in PA studies?

Researchers have increasingly used GPS to record locations of participant PA, yet few best practice recommendations exist for these devices. Importantly, evidence to support a recommendation for the necessary monitoring length is lacking, with researchers typically relying on recommendations derived for accelerometers when developing study procedures. This research suggests that monitoring may need to be longer for many locations of particular interest for PA. In particular, reliable estimation of PA minutes on roads or in parks may require up to twelve days of monitoring and minutes in homes near 20 days. Therefore, researchers implementing GPS to record adult PA locations should increase monitoring time above what is current common practice.

Strengths

As described in the literature review (Table 1), the three methodologic issues addressed by this research fill noticeable gaps in the research of the locational context of PA. Namely, a device-based study of US adults from an expanded geographic scope is a significant addition to the body of literature examining the locations of adult PA. Understanding the spatial overlap between commonly used residential buffers and true PA space provides much needed information about the appropriateness using residential buffers to assign built environment exposures for PA. Finally, recommendation of the number of GPS monitoring days in a field currently lacking guidance on this important study design decision is an important addition to the literature.

All three aims leverage joint accelerometer and GPS data collected over three weeks from a sociodemographically and geographically diverse participant sample. This sample therefore improves generalizability over the existing studies described in the literature review for

Specific Aims 1 and 2 (Tables 1 and 2). Further, this sociodemographically- and geographically-diverse participant population was leveraged to present results for Specific Aims 1 and 2 by key characteristics that may be important to future intervention planning. Also, the data collection relied on accelerometers and GPS to objectively measure PA and locations, limiting impacts of self-report such as recall bias or social desirability bias.

New tools and concepts were developed for this research that can be used in future studies on the topic. The coding protocol developed for this study, which was facilitated by the high performing GPS units, allows detailed assessment of PA locations, providing a more comprehensive view of PA location use via objectively recorded data than has previously been reported. This protocol will be included in the published paper, allowing implementation in future studies on this topic. Additionally, a new definition of PA space was proposed that may better represent the true spatial area in which PA occurs. In this context, PA space is created by constructing the minimum convex polygon for each bout of PA and then dissolving these polygons into a single layer. This definition of PA space can be used in place of residential buffers for assigning built environment exposures to PA behaviors within Geographic Information Systems (GIS).

Limitations

A limitation common to all three aims is that although SOPARC is a large sample of geographically- and sociodemographically-diverse adult participants, it is not a representative sample, meaning the results presented here based on socio-demographic or geographic characteristics may not be representative of these groups. The largely park-based participant selection method limits generalizability to the United States population as a whole. Nevertheless, analyses suggested that those recruited from parks did not use parks more for PA over the three weeks of monitoring than those recruited from nearby homes, providing some mitigation to these concerns. Also, the focus of SOPARC on adult PA limits applicability of these results to children and adolescents.

Selection is of particular concern for analyses considering VPA given that expected patterning of VPA by sociodemographic characteristics was observed. Most participants who engaged in VPA were younger, white, highly educated, and non-obese. As a result, examination of sociodemographically stratified results was limited in many cases due to limited sample size. Potentially contributing to the patterning in VPA was the use of standard definitions of PA intensities, meaning that the definition of VPA was not based on age or BMI. As such, the small number of seniors and obese individuals with VPA may be an underestimate of true VPA in these populations (90).

Another limitation is that accelerometers do not capture all forms of physical activity. For example, the units used in this study were not waterproof and therefore had to be removed before swimming. Additionally, the accelerometers do not consistently capture all instances of some physical activities, for example often missing some biking and weightlifting. For physical activities that were recorded, the newly proposed location coding protocol was used to classify locations of PA. Although this location coding protocol was implemented by a single coder to ensure consistency of interpretation of the coding protocol, examination of reliability across multiple coders was not possible.

Several participant characteristics correlated with recruitment site, making geographic and sociodemographic patterns difficult to disentangle in most analyses. Further, two sites (Ohio and Pennsylvania) had lower GPS compliance than the other sites, resulting in a substantial portion of missing data at these sites. Differences were noted by recruitment site in most analyses, further suggesting that these concepts may vary over space, potentially limiting generalizability of the results observed in these analyses to other locations. These geographic differences could in part be due to seasonality or weather, although attempts to control for this were made by collecting data only during the spring, summer, and fall.

As with much built environment research, a limitation of examining the locations of PA is that a causal relationship between a location type and PA is not established with this research. Nonetheless, the results identify the locations in which participants chose to engage in PA over a three week period. Regardless of whether there is a causal association whereby these locations influence PA, these places do currently support PA for these participants. Therefore, it is important to consider them in future studies and in intervention and policy planning.

In examining the spatial overlap between PA spaces and residential buffers, focus was placed on MVPA using a threshold that likely includes PA achieved through moderate activities of daily living. These results may not directly apply to more purposeful PA at higher intensities. Nevertheless, results consistently suggested a poor match between PA space and residential buffers, even after removing PA occurring at home. These results also only inform comparison of PA space with residential buffers, limiting generalizability to activity spaces for other health behaviors.

Due to limited sample size, recommendations for length of GPS monitoring time could not be stratified by sociodemographic characteristics. It is possible that some groups may require less monitoring than others, supporting future research within larger samples of specific sociodemographic groups.

Despite these limitations, the previously described strengths indicate that this research contributes significantly to the field of PA research both in substantive and methodological terms. The SOPARC GPS sub-study participants are more geographically and sociodemographically diverse than many of the previous populations studied for these topics, and this research provides several new tools and concepts that direct the field towards more methodologically sound measurement practices.

Public Health Significance

Many studies have linked PA to prevention of a spectrum of chronic diseases, compression of morbidity, improved quality of life, and reduced healthcare costs (1, 105). Yet most adults do not engage in the recommended amount of PA and a significant number participate in no leisure time PA (4, 5). While it is clear that changing technology has played a large role in reduction of PA at the population level, public health practitioners have been unable to develop interventions that successfully reintegrate sufficient PA into the lives of adults at the population level. Much research is therefore conducted in an attempt to understand how to motivate PA in diverse groups of people.

Specific Aim 1 provides valuable information for public health practitioners attempting to implement the Community Preventative Services Task Force recommendations to increase PA at the community level. Understanding the locations in which sociodemographically and geographically diverse adults choose to be physically active can help to tailor individually-adapted health behavior change programs, locate communities appropriate for community- and street-scale urban design and land use policy interventions, and identify groups amenable to social support interventions in community settings

Aside from understanding the specific locations that support PA, knowledge of the built environment characteristics of those locations is also important in developing interventions and environments that can successfully influence PA. Unfortunately, much research on these built environment characteristics has yielded inconsistent results, making decisions about appropriate intervention and urban planning difficult. Specific Aim 2 therefore examined one of the potential causes of inconsistency in the literature, the use of residential buffers to assign built environment exposure to PA, and proposes the new concept of PA space as a more appropriate alternative. In examining the spatial overlap between these buffers and GPS-derived PA spaces, Specific Aim 2 addresses this issue in a more direct way than has previously been published. The results of this aim will therefore hopefully guide researchers into a more methodologically sound method of conducting built environment research, ultimately resulting in information that can accurately inform intervention and urban planning efforts.

In order to continue producing scientific evidence about PA locations and the characteristics of those PA locations that influence PA, many researchers have turned to GPS devices to objectively record the locations in which PA occurs. As observed in Specific Aim 2, this practice must continue in order to develop spatially accurate PA spaces, yet few recommendations exist for appropriate study practices involving GPS. Specific Aim 3 therefore contributes to efforts to ultimately develop effective interventions at the community level by providing a recommended GPS monitoring period for studies examining the locational context of PA. This goal of this recommendation is to ensure that the data used to inform intervention development and urban planning is accurate and reliable, increasing the likelihood that these efforts will be successful in increasing PA at the community level.

Future Directions

The tools, concepts, and findings of this dissertation provide a strong foundation for continuing study of the locational context of PA. Much additional work within the SOPARC GPS sub-study is possible. Further, the methods used and results found can be applied to studies of the locational context of PA in other settings.

Future work within this data source includes more detailed examination of the PA locations recorded with the newly developed PA location coding protocol. For example, future papers may examine the specific park amenities used for PA (tennis courts, footpaths, open space, etc.) and the characteristics of the most frequently used roads (road size, presence of sidewalks or bike lanes). Future analyses in this dataset may also investigate the modifiable areal unit problem in this setting by comparing the minimum convex polygon definition of PA space with other spatial summarization methods, such as standard deviation ellipses, to determine if and to what degree the definition of PA space affects the relationship between PA space and residential buffers.

In other settings, future work can incorporate the newly-developed PA location coding protocol to extend the depth of knowledge about locations of adult PA. The results reported here can also be used along with important CPSTF recommendations for PA interventions to appropriately target these interventions based on sociodemographic and geographic patters of PA location use. Future studies examining the effect of the built environment on PA can use the results from this work to support assignment of built-environment exposures using the proposed PA space concept as opposed to exposure assignment based on residential buffers. Further, studies examining the locations of adult PA as well as the effect of built environment exposures on PA should both collect location data using the GPS monitoring recommendations laid out in

Specific Aim 3. Importantly, the questions examined in this research could also be explored in studies of children and teenagers to explore whether the conclusions derived for adults extend to this younger population.

Conclusions

In conclusion, the substantive and methodological contributions of these three inter-related aims act to improve the PA locational context literature. These results facilitate current PA intervention development and urban planning by noting the locational contexts in which sociodemographically diverse adults choose to be physically active. Further, they guide future research practices to improve the methodological soundness of studies examining the locational context of PA, both in providing a more accurate spatial summarization of PA space from which built-environment exposures can be derived and in recommending the length of GPS monitoring needed to reliably estimate PA locations. Taken together, these results provide useful information for researchers, health promotion specialists, and urban planners attempting to study and plan environments that support PA.

APPENDIX: SOPARC GPS SUB-STUDY

UNC IRB Approved

Physical Activity Location Coding Protocol
Last Updated: January 20, 2015

Katelyn Holliday, MSPH

Contents

Purpose

The SOPARC study collected data from adult participants in five states (NC, NM, OH, PA, and CA). These participants wore an accelerometer (measures physical activity level) and a GPS (records location) for up to three weeks. Both instruments recorded data every minute. We are interested in determining the types of locations in which the participants were moderately or vigorously active. Further, we are only interested in physical activity that occurred for an extended period of time, a "bout," which we defined as at least ten minutes of physical activity (with allowance for up to 20% of the time to be below moderately active). The dataset therefore contains a list of GPS points that are part of these physical activity bouts. We will be using Google Fusion Tables to map and identify the types of locations in which these bouts of physical activity occurred. This procedure provides instructions for coding the locations.

Data Security

All data security protocols mentioned in this protocol must be strictly followed to comply with IRB regulations. All work must be done from a secured location using an encrypted computer.

Table 1. Needed Data File Variables

Name	Description	Coding
LATITUDE	Latitude from GPS	Numeric; degrees
LONGITUDE	Longitude from GPS	Numeric; degrees
SPEED	Speed from GPS	Numeric; km/hour
TIMESTAMP	Time stamp	DD/MM/YYYY hh:mm:ss
ACTDAY	Monitoring day number	Numeric; possible 1-21
bout_ID_new	Physical activity bout number; numbering restarts each ACTDAY	Numeric; possible 1-X, where x=number of PA bouts during a given day
WEEK	Monitoring week number	Numeric; possible 1-3

Table 2. Variables To Be Coded

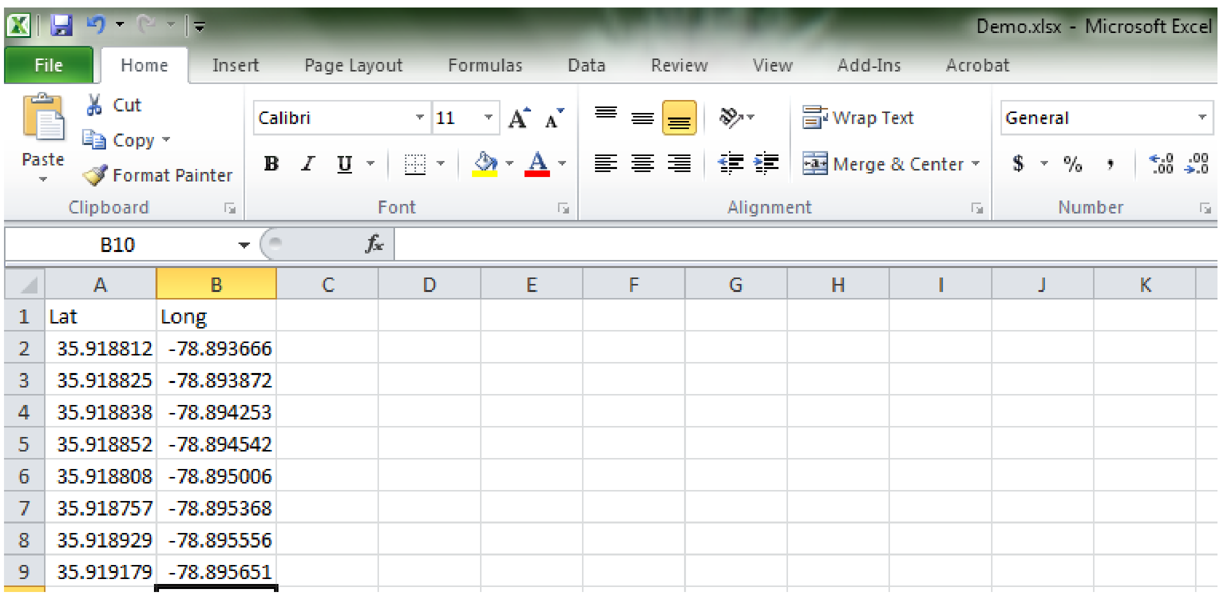
Name	Description	Coding
Main	Main physical activity location descriptor	Character; see options below
RoadType	Sub-variable identifying the type of road for observations with Main=road	Character; single, double, gt2ln
Notes	Sub-variable identifying location type for observations with Main=other	Character
Sidewalk	Indicates presence of a sidewalk	Character; yes, no
BikeLane	Indicates presence of a bike lane	Character; yes, no
School	Sub-variable identifying location type for observations with Main=school	Character; see options below
Imputed	Identifies whether the location code was imputed from missing GPS data	Character; yes, blank
SchoolType	Indicates the type of school for observations with Main=school	Character; see options below

1. Open the data file containing the GPS and physical activity bout data as well as a blank excel document to be named Shell_Sheet.xlsx

2. From the data file, highlight the latitudes and longitudes comprising a single bout and copy and paste these into the Shell_Sheet file under headings of latitude and longitude.

   Note: The variable bout_ID_new indicates the bout number. This variable restarts numbering each ACTDAY.

3. Save the Shell_Sheet file in an encrypted space.



4. Open Google Chrome

5. Open a “New incognito window” in Google Chrome (ctrl + shift + n)

6. Paste the link in the incognito window https://www.google.com/fusiontables/DataSource?dsrcid=implicit&folder=0ANbYRqoiHVLJUk9PVA&pli=1

7. Log on using your Google (Gmail or Googledocs) username and password.

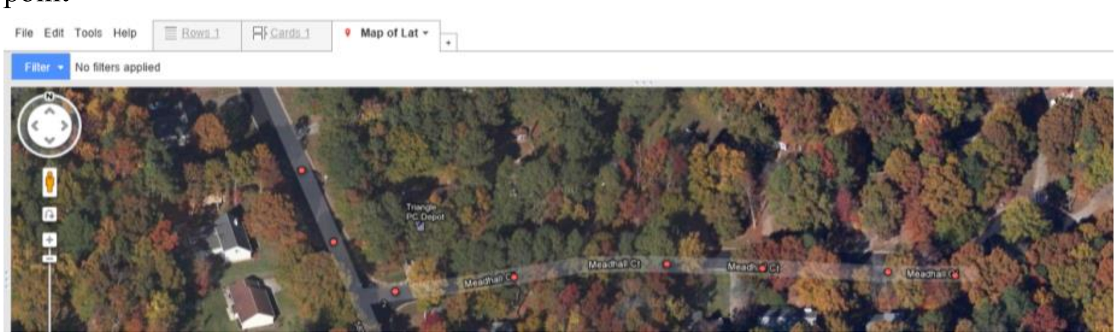
8. “From this computer” will be highlighted on left. Click “Choose file” on right and navigate to the Shell_Sheet file in the box that opens. Select the file and click open.

9. Click next at the bottom of the page.

10. Click next at the bottom of the page.
11. IMPORTANT: on the next page DESELECT "Allow export"! This keeps the data private and ensures others cannot download it. Click Finish.

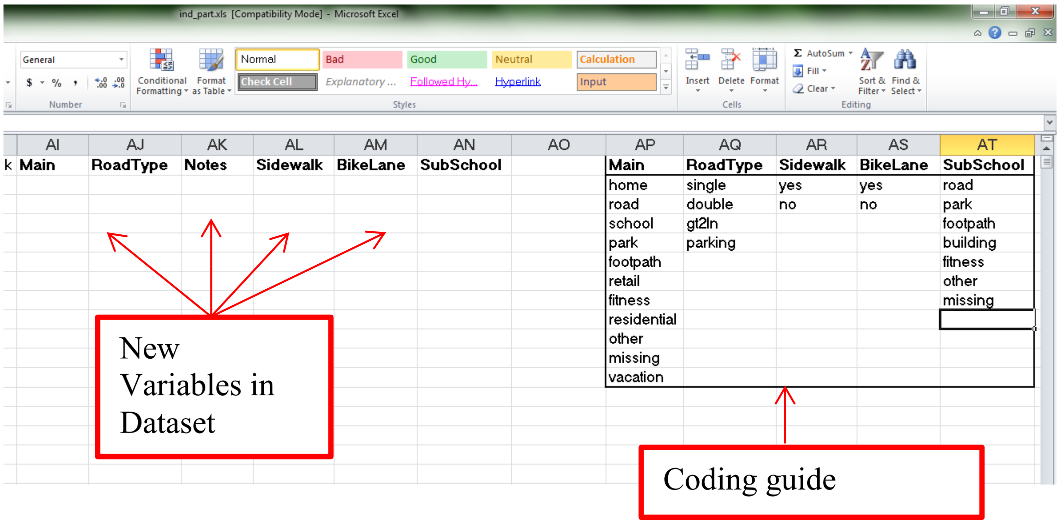
12. Click on the "Map of Lat" tab

13. Use the Google Maps tools to best view the locations of the red points
    <u>Zoom Tool</u>: Click +/- buttons (upper left) to zoom in and out
    <u>Street View Tool</u>: Click and drag yellow man (upper left) to a street to enter street view, click "X" in upper right to exit street view
    <u>Satellite</u>: Click "satellite" and "map" buttons (upper right) to toggle between satellite and map views.
    <u>Point Selection</u>: Click on a red dot to view the Latitude/Longitude corresponding to the point



14. Follow the Location Coding Protocol to determine the correct codes for the points

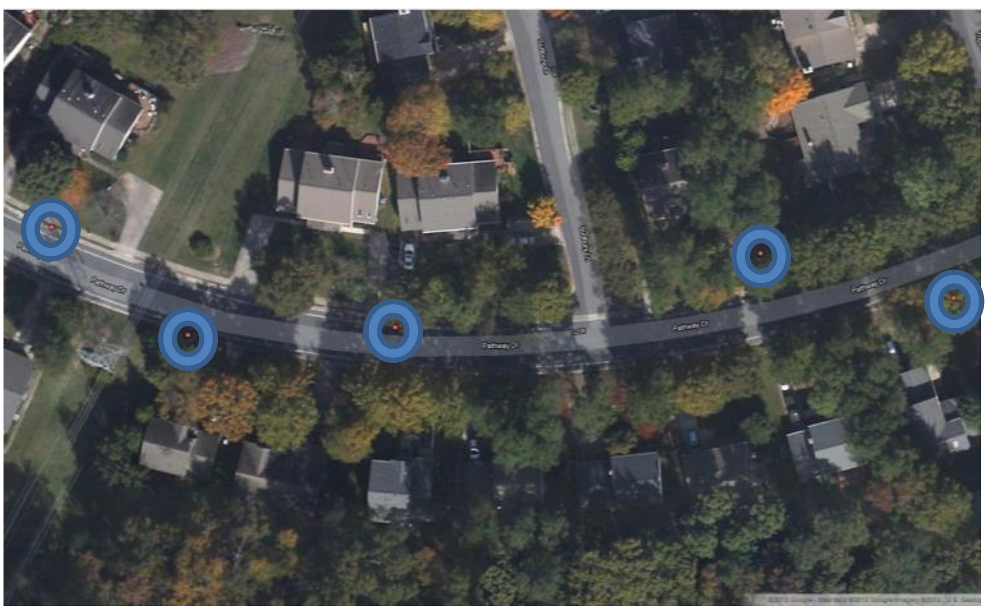
15. Record these codes in the data file under the column headings **Main**, **RoadType, Notes**, **Sidewalk**, **BikeLane,** and **SubSchool**.



The following protocol provides instructions for broadly classifying physical activity locations as home, road, footpath/trail, school facility, park, retail location, fitness center, non-home residential area, or other location. Points that occur along a road will be further classified to describe the size of the road (single lane, double lane, greater than two lane road, or parking lot) as well as to indicate the presence of sidewalks or bike lanes. Additionally, points coded as school will be further described to indicate the specific type of location. Finally, notes will be taken to describe the "other" locations.

To accommodate for potential GPS inaccuracy, an entire bout will first be viewed to ascertain the overall pattern of points (i.e. do the points indicate forward travel or are they clustered in one area). An entire bout of points need not receive the same code for each point; however consideration of the whole bout in making point-by-point coding decisions is acceptable. GPS inaccuracy is especially likely in areas with dense tree coverage or tall buildings (viewable on the satellite imagery), but is also affected by daily weather conditions.

> For example, the overall pattern of points below suggests that the person is travelling along the road. However, if we were to look at each point individually, some would appear on the road and some in nearby yards. Here we will use the pattern of the bout to make the decision to code all the points below as occurring along a road.



1. Examine the pattern of points in the entire bout, particularly considering whether the points cluster in one area or if they make up an obvious travel bout

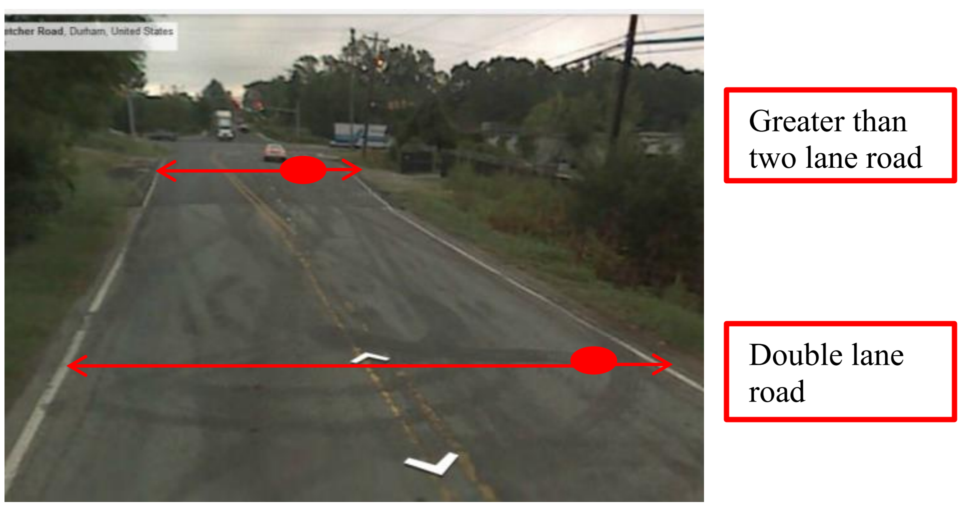
2. If the points follow a **road**, in the data file

    a) Code “road” under the **Main** column

    b) Zoom into street view and determine the type of road **(single, double, greater than two lane road, or parking)**

    c) Code “single,” “double,” “gt2ln,” or “parking” as appropriate under the **RoadType** column in the data file

    Coding Explanation: Look for the number of lanes, according to painted lines, at the exact point location. Do not consider parking lanes as a separate lane. The number of lanes may change for the points in a bout. For example, the bottom point below would be coded as a double lane road and the top point would be coded as a greater than two lane road even though the points are in the same bout



    d) Zoom into street view to look for the presence of sidewalks, bike lanes, and shoulders.

    e) Code “yes” or “no” as appropriate under the **Sidewalk** column in the data file

    Coding Explanation: Look for the presence of a sidewalk, on one **or** both sides of the road, where the exact point is located. This coding can be different for points in the same bout as below:

Sidewalk
Yes

Sidewalk
No

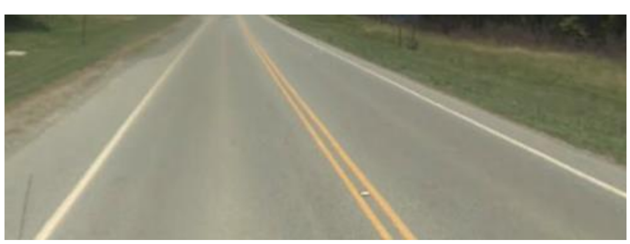
f) Zoom into street view and look for the presence of a bike lane or shoulder

g) Code "yes" or "no" as appropriate under the **BikeLane** column in the data file

Coding Explanation: Look for the presence of a designated bike lane or a shoulder wide enough for bicyclists to ride without interfering with the flow of vehicle traffic. Bike lanes are typically designated by a solid white line with a picture of a cyclist painted near an intersection. Shoulders are also typically designated with a white line:

Bike Lane
No
Shoulder too narrow

Bike Lane
Yes
Designated bike lane with cyclist picture and white



Bike Lane
Yes
Wide shoulder designated by white lines

Notes for coding a road bout

Road bouts often have a point or two at the beginning or end of the bout that remain stationary on the starting/ending location. If there are two or less of these points, code them as road points corresponding to the nearest road, even if they are at a starting/ending destination. If there are more than two points, code them following the below protocol for points that are clustered in one location.

Similarly, road bouts often have points at the beginning or end that are no longer on the road. If these points are still making forward progress, and therefore do not fall under the directions for the above note, code the points as follows: If the points are in a parking lot or other non-street area *designed for cars*, code the points as Main=road, RoadType=parking. If the points fall in another location, code them according to the protocol for clusterd points below.

Do note that if middle points fall off of the road, they can receive a different coding cateogry. For example, if the bout is along a road, but takes a detour along a footpath/trail, code the points along the footpath/trail as Main=footpath.

3. If the points are clustered around one location, in the data file

a) Code "home" under the **Main** column if the points occur in or around the participant's home.

Coding explanation: To determine if the location is the participant's home, open a **different** browser type (i.e. if you are in Google Chrome, open Internet Explorer or Mozilla Firefox). Go to www.google.com/maps and ensure you are **not** signed into Google in this browser (otherwise Google will remember the point). Open the HomeAddress excel file from the encrypted space. Locate the latitude and longitude corresponding to the appropriate participant ID (compare the sheet name in the data file with the ID column in the HomeAddress file). Copy this latitude/longitude pair into Google Maps and determine if the Fusion-mapped activity point is at the participant's home.

Note: The **green** arrow indicates the latitude and longitude point you mapped whereas the red balloon just represents the nearest address to the GPS point. Therefore, the **green** arrow represents the participant's home.

For individuals who live in apartment buildings or attached townhomes, compare the bout to what it would be like if the person lived in a single-family detached home. If the points cluster around the building, including nearby grassy areas or the street/cul-da-sac, code Main=home. This type of location is similar to activity occurring in the yard of a single family detached home. If the points are a forward motion travel bout that travels along the road/parking lot network within the complex, code Main=road as described above. This type of location is similar to travelling on streets around a neighborhood of single-family detached homes. Remember that GPS accuracy is less likely for points occurring inside an apartment/townhome building, so clustering of points can be somewhat dispersed. The key difference is looking for a clump with no pattern versus a directed route along a road network as seen below:

Main=home
Although some points are on the road and some are in the green space, they all cluster around the home

Main=road
Although the points are all within the complex, they are distinctively along the road network

b) Code "residential" under the **Main** column if the points occur in or around a residential location (e.g. a single family home or apartment complex) that is not the participant's home

c) Code "park" under the **Main** column if the points occur in a park.

Coding explanation: Look at both the map and satellite images as Google often colors park land green on the map view, but it does not always match up precisely with the actual physical park boundaries, which are often visible on satellite view by looking for amenities like baseball and soccer fields. Remember coding choices should be based on the whole bout. Some participants live near parks. If the bout is mostly at home, but a point or two strays into the edge of parkland, code the whole bout as Main=home. Similarly, if the bout is mostly at a park, but a point or two strays outside of the park boundary, code the whole bout as park. The IN_PARK_FLAG can aid in determining if the area is a park, but the point-by-point designation does not have to match this variable.

d) Code “retail” under the **Main** column if the points occur in a retail “big box store” location.

Coding explanation: Look for points clustering over retail locations (e.g. Target, Lowe’s, etc.). These stores are usually stand alone, but can be a part of a strip mall. Only code the points as retail if they appear to be in the big box store location. Remember that GPS accuracy will likely be poor for points occurring inside these large buildings, meaning points may be scattered over the building, parking lot, and surrounding area. Code all of these points as retail.

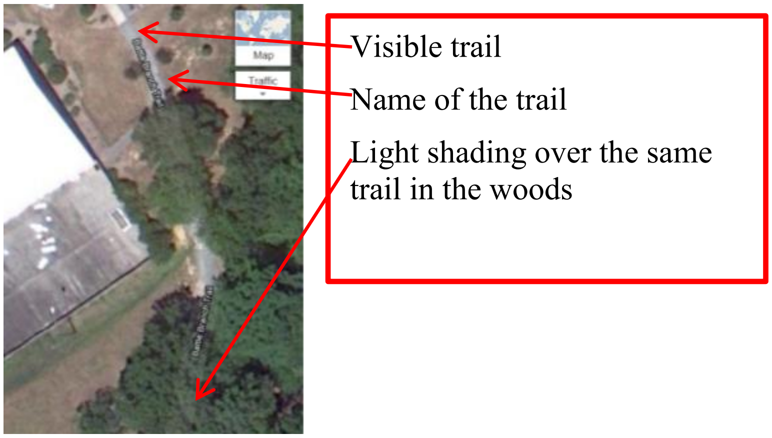
e) Code “fitness” under the **Main** column if the points occur in a fitness facility (e.g. O2 Fitness, YMCA).

Coding explanation: Similar to retail locations, look for points clustering around fitness facilities and code all points (e.g. over building, in parking lot) as “fitness.” In the **Notes** column record the name of the facility.

f) Code “footpath” under the **Main** column if the points occur along a footpath or trail located outside of a park.

Coding explanation: A footpath/trail is distinct from a city sidewalk that occurs along a road. Google does map some footpaths/trails in the map view. Footpaths/trails are also sometimes visible from the satellite or street views. If the footpath/trail is covered by trees, Google sometimes indicates its presence by light shading over the trees and/or by displaying the name of the trail. Coding Main=footpath can occur for all points in a bout or for selected points in bout with other codes.

Light shading over a trail in the woods



g) Code “school” under the **Main** column if the points occur on school property

   Coding explanation: School can comprise any level of education, including college campuses. As with parks, looking at both the map and satellite views may be useful as Google colors most universities a gold/tan color. After coding all points on the school grounds as Main=school, code the **School** column to specify the location type further. The possible sub-classifications are road, footpath/trail, building, park (which includes greenspace), fitness, other, and missing and should be coded based on the preceding descriptions of these variables. For building, consider the cluster classification scheme described for retail. For road, fill out the RoadType, Sidewalk, and BikeLane variables as appropriate. If it is impossible to distinguish where the points are (because of e.g. GPS error due to tall buildings) code Main=school and School=missing). In addition, code the **SchoolType** variable according to the type of school: pre-K, elementary, middle, high, community college, university. If the school is a church academy that doesn’t meet these standard definitions, in **SchoolType** describe the age range.

h) Code “commercial” under the **Main** column if the points occur in a commercial, non-retail location.

   Coding explanation: If the points cluster over a commercial location (a non-big box store, restaurant, etc.), code the points as commercial. In the **Notes** column, further describe the location as: hotel, gas station, strip mall, store, restaurant, or dense (meaning many shops, restaurants, etc. are clustered together in an area that doesn’t meet the definition of a strip mall, density prevents identification of the precise location).

i) Code “mixed use” under the **Main** column if the points occur in a *planned* mixed-use area.

   Coding explanation: Mixed-use areas have shops, restaurants, housing, and other amenities like movie theatres or banks. In this case we are looking for purpose developed mixed-use areas that are typically advertised as such. The area must contain housing to qualify here, otherwise it would be coded as a strip mall or commercial (dense).

j) Code “other” under the **Main** column if the points occur in a location type not listed.

Coding explanation: If the location type does not fit any of the pre-defined categories, code Main=other. Then in the **Notes** column, attempt to describe the location. Choose from the following notes: office (for buildings that appear to house offices but not commercial businesses), entertainment (for things like fairgrounds, stadiums, casinos, etc.), airport, healthcare, library, golf course, church, or factory (for factory or warehouse). If the listed notes do not describe the location, create a new note.

k) Code “vacation” under the **Main** column if the points occur greater than 35 miles from their home address

Coding explanation: Since we are interested in coding usual locations of physical activity, we do not want to consider activity that occurs while the participant is travelling. Therefore, if the physical activity occurs far from home we will not classify it. An exception is someone who is obviously commuting a large distance for work. This would be visible by having long distance physical activity that regularly occurs in the same location throughout the entire monitoring period, with other points occurring at home on the same days. In this rare case, the raw data can be checked to determine if the participant returned home each day.

l) Code “missing” under the **Main** column if the points cannot be classified

Coding explanation: Some points will be missing latitude and longitude. If there are only a few points like this within a bout, attempt to classify them. For example, if all of the points cluster around a retail location and a few middle-of-the-bout points are missing, they can be coded as Main=retail. When you do this, code “yes” for **Imputed**. If points for the entire bout are missing latitude and longitude, examine the raw SAS file for the last and next recorded GPS point. Consider the length of time between these points and the bout. Consider the locations of these points. Classify the missing GPS points if you feel confident to do so. For example, if the last point was 20 minutes prior to the bout and at Whole Foods and the next point is 2 minutes after the bout and at whole foods, you may code the points as **Main=**“retail” and **Imputed**=”yes”. However, if the last point is 3 hours prior and the next 3 hours after the bout and both are at the participants home or are at different locations, then the points cannot be imputed. Code **Main**=”missing” and **Notes**=”do not impute.”

m) Code “motorized” or “remove” under the **Main** column for motorized points as described below.

Coding explanation: Occasionally motorized points will be included in a bout. These could be legitimate minutes in a motorized vehicle during an activity bout (with **bout_flag**=0) or inaccurate accelerometer readings while in the motorized vehicle (with **bout_flag**=1). For any point that has **Speed**> 50 kmh, change the

bout_flag point to 0 if it is a 1. Check to see if the points still meet the definition of a bout. Remember that the entire string together does not have to be a bout, but that every point in it must be part of a bout. For any bouts with points in the 20-40 kmh range, plot the bout and determine if it is moving along a road. If so, identify the segment of the bout that contains road travel. In the excel file, choose an empty box and type =percentile(array, 0.75) where for array you highlight the speeds for the points in the road travel segment. If the 75th percentile returned is >25 kmh, change to **bout_flag**=0 for any points that have **bout_flag**=1. Again, check to see if the points still meet the definition of a bout. Any points that must be removed because they no longer meet the definition code **Main=**remove, **Notes**=motorized. This includes both the motorized points and stationary points that may not be in a bout now that the motorized points have changed to **bout_flag**=0. If the motorized points are still part of a bout (i.e. there were only a few so that they did not cause the bout to drop below 80% active) then code **Main**=motorized.

General Note: If at any point you suspect a set of points may represent the participant's work (e.g. they have spent 5 hours at Whole Foods or a day care), at the word "work" in with any other notes in the **Notes** column.

1. After coding a bout, click the down arrow next to “Map of Lat” and select “Remove.”

2. Click on the “Rows” tab

3. Select the “Edit” tab

4. Click on “Delete all rows”

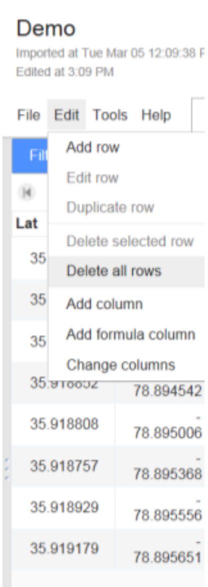
5. Select “Delete all rows” in the box that opens

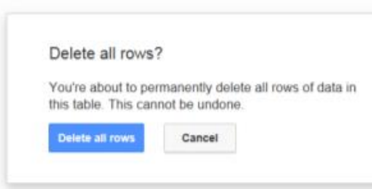
6. Verify that rows were deleted

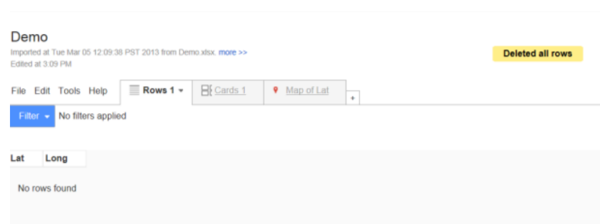
1) Select “Delete all rows”

2) Confirm permanent

3) Verify rows were deleted







<u>Notes for Removing Data from Google Fusion</u>

Sometimes an error occurs and a red warning pops up saying “Could not delete all rows.” If this happens, select a row and 3 icons will appear in the row. Click on the trash can to “delete the row.” When you do this, it fixes the issue and deletes the rows. Also, note that this process saves a file in your google drive. Since we remove the points, the files are empty, but they take up “upload” space. You will need to periodically delete them or you will get an error saying “Upload exceeded.”

7. Click “File” and select “new table”

8. Close the tab you were working in

9. Repeat the entire process in the new tab that opens

   <u>Security Note</u>s: Each time we are resaving over the Shell_Sheet file and only saving data from one bout in that file. We are also deselecting the "Allow export" option during the import process to keep the data private. Finally, we are deleting the data from the Google table each time so as to not save data on Google.

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